A SURVEY AND ANALYSIS OF HIGH DENSITY STORAGE DEVICES

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THESIS

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OF
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by

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ABSTRACT

With the need for storage of greater volumes of data, new technology has emerged in high density recording of data. First, a review is made of the conventional magnetic storage devices, including tapes, drums, and discs, and their double density replacements. A detailed analysis of disc storage devices is included. Mass storage units with very high recording densities will then be discussed. First, the different approaches taken toward mass storage will be presented, followed by an example of each approach. Finally, one of these example systems, a laser mass memory system called UNICON, will be analyzed with respect to file organization and I/O routines.

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I. INTRODUCTION

A need has arisen for peripheral units with larger data storage capabilities. As a result, a new technology in high density storage has evolved. The application of high density techniques to conventional peripheral storage devices, such as tapes, drums and discs, will be discussed first. A descriptive survey will be provided for tape units and drum units offered by the different manufacturers. A detailed survey and analysis of disc units will be presented also in the first section of this report.

Mass storage devices will be examined which utilize new techniques and technologies in data storage. The different approaches taken toward attaining a trillion bits of storage will be discussed, as well as example systems of each method being presented. Finally, one of these mass memory systems, the UNICON, will be analyzed with respect to different I/O routines, such as data retrieval and file maintenance.

The basic objectives of this research were:

(1) to describe the current trend, in magnetic recording, of storing greater amounts of data into the same surface areas. Explicitly, to describe double density recording devices as replacements for conventional magnetic recording devices,

(2) to demonstrate the performance and cost effectiveness of the disc storage devices offered by the independent

manufacturers, i.e., those manufacturers not involved in mainframe construction,

(3) to view the progress of new technologies have made possible, in the field of mass storage devices. To determine what technologies are being used and to determine what mass storage devices are available in the near future.

(4) To take as an example mass storage, the UNICON mass memory, and to analyze its performance in regards to data retrieval, file maintenance and report generation, with regards to a given file organization.

II. MAGNETIC HIGH DENSITY RECORDING, CURRENT STATE OF THE ART

A. MAGNETIC TAPES

1. Recording Techniques

Several recording methods have been developed and are in general use, for digital data recordings on magnetic tape. These methods are classified as saturation and non-saturation (biased) recording.

Saturation recording techniques are the conventional method of recording digital data for computer data storage on magnetic tape. With this method each recorded pulse saturates the oxide of the tape completely and no part of the tape is partially recorded or unrecorded. Each pulse is identified by its magnetic polarity, which is established by the direction of the current flow in the record head. When tape is moving and the record head current direction is rapidly reversed, a series of small magnetic particles (magnets), each with opposite north/south polarity, is left on the tape as a permanent record of the current changes.

An effective technique for recording each change from a zero to a one or vice-versa is indicated by a full flux transition. With this system, a string of ones will show no transition, nor will a string of zeroes. However, a transition will take place each time a one follows a zero or a zero follows a one. The NRZI or "non-return to zero

mark", is a variation of NRZ in having a flux transition for each one, with no transition for a zero. This method is efficient, relatively error-free, and capable of densities up to 1000 transitions per inch. It represents the bulk of present-day digital recordings used for computer. Both NRZ and NRZI encoding share one common problem which affects data accuracy. In NRZ, a long string of ones or zeroes, and in NRZI a long string of zeroes, result in signal pulses of extremely long duration. This can result in inaccurate data during these long periods without change in flux direction.

In order to overcome the deficiencies of NRZ and NRZI encoding discussed above, another saturation recording technique called phase-encoding, has been used. The phase-encoding technique provides at least one flux transition for each bit cell. This technique represents a one as being a positive pulse and a zero as being a negative pulse. Since a lack of data causes no pulse to be generated, this method allows a positive distinction to be made between a "no bit" and a zero bit, which could not be done with NRZI recording. Also, this technique requires a phase reversal to the "no bit" condition after each bit so that sequential ones or zeroes can be recorded without using very long pulses. Thus, 1600 bpi phase-encoded tapes actually have 3200 phase reversals per inch compared to 800 phase reversals per inch with 800 bpi NRZI tapes. Phase-encoding has other advantages, such as restricted bandwidth, and lower operating thresholds,

which make it an inherently more reliable technique. These properties also make it possible to operate at higher packing densities; hence, the current use of 1600 bpi in phase-encoded systems.

2. Present Devices, IBM Tape Drives Available

A tape transport can be said to be IBM compatible if any tape recorded on that transport can be read on a similar type IBM transport, and if tapes recorded on the IBM tape transport can be read on the transport under consideration. What this is really saying is that compatibility will permit completely free inter-changeability of tapes between transports regardless of who manufactured them. IBM compatible as a phrase should ~~be~~ be confused with IBM plug-to-plug compatible. The first phrase, as defined above, is limited to the interchangeability of tapes; while plug-to-plug compatible relates to the interchangeability of both the tapes and the transport system-transports, controllers, interfacing. As "plug-to-plug" infers, the hardware itself is physically compatible; unplug one and plug-in the other.

The freedom of tape interchangeability is mandatory from the viewpoint of most users. Any application that involves generating tapes in one location and reading them in another requires that successful operation not be dependent on a specific transport. There is no necessary reason why tapes must be IBM compatible. Any format and coding scheme could be carefully defined and specified and

manufacturers could then design and build to that standard. However, from a practical standpoint, the dominance of IBM in the computer market has resulted in standards established by IBM becoming accepted by most of the industry.

IBM currently offers three tape series for the systems 360 and 370 computers: 2401, 2420 and the 3420 series. In all three series, data is recorded on half inch wide magnetic tape on 9 tracks. The 3420 series also offers 7-track recording. In the 2401 series, models 1, 2, and 3 record at 800 bpi in an NRZ format and have tape speeds of 37 1/2, 75 and 112 1/2 ips, respectively. Models 4, 5 and 6 are dual-density drives using either NRZ and phase-encoded format, recording at 800 and 1600 bpi, and having tape speeds of 37 1/2, 75 and 112 1/2 ips. The 2420 series comes in two models: the Model 5, which operates at 100 ips and the Model 7, which operates at 200 ips. Recording format for both 2420 models is 1600 bpi and phase encoded. The 3420 series features dual-density recording, either 9-track, 1600 and 800 bpi, or 7-track, 800 and 556 bpi. Three models of the 3420 are offered: the Model 3, with a tape speed of 75 ips; the Model 5, with a speed of 125 ips; and the Model 7, with one of 200 ips. Transfer rate of a device is a function of the speed and the linear density; the higher the two components, the higher transfer rate. As a result, the 2420-7 and 3420-7 offer transfer rates of 320 thousand bytes per second. The 2401 series offer transfer rates as high as 180 thousand bytes per second.

3. Summary of Double Density Tape Drives

A survey of independent manufacturers' tape units that use double density recording (1600 bpi) could be categorized into the following IBM compatible groups: 2401 - 5, 6,; 2420 - 5, 7; and the 3420 - 3, 5, 7. Two manufacturers, Storage Technology and Telex even went a step further, offering models that have no direct IBM counterpart but use plug-to-plug compatible with the Systems 360 and 370. These models offer transport speed (transfer rate) options that split the 2420 - 5 to 2420 - 7 and 3420 - 3 to 3420 - 7 operational spectrum. The tape units found are listed in Table I. according to manufacturer and compatible groups.

All tape units in the table are available with a recording density of 1600 bpi. The characteristics of the IBM compatible tape drives listed in Table I, may be summarized as follows:

a. Phase encoding is used with 9 track, 1600 bpi tapes.

b. NRZ recording is used with 9 track, 800 bpi and 7 track, 556 or 800 bpi tapes.

c. The 2401 - 5, 6 and the 3420 - 3, 5, 7 compatible groups all provide a single density (1600 bpi) and dual density (800 and 1600 bpi). The 2420 - 5, 7 groups provide only 1600 bpi density for 9 track tapes.

d. In addition to providing dual density for 9 track tapes, the 3420 - 3, 5 and 7 groups provide dual density (556/800 bpi) for 7 track tapes.

TABLE I

SELECTED MANUFACTURERS OF COMPATIBLE TAPE UNITS

ufacturer	Tape Type and Model Number (IBM)						
	2401-5	2401-6	2420-5	2420-7	3420-3	3420-5	3420-7
ex	TM 1624V TM 20405	TM 1624VI TM 20406	TM 20245	TM 20247			
ter	SC 2405	SC 2406	AT 2425	AT 2427	AT 3423	AT 3425	AT 3427
ex	4852	4862	5420-5	5420-7			
as truments	924-5	924-6			934-3	934-5	934-7
rage hnology		ST 2460	ST 2450	ST 2470	ST 3430	ST 3450	ST 3470
a Processing ancial and eral		DPF 2406	DPF 2425	DPF 2427			
ode (OEM)				2024-7			

e. All 9 track tapes employ a .60 inch inter-record gap, while 7 track tapes use a .75 inch inter-record gap.

f. Except for Telex, all tapes read backwards.

g. Automatic threading is available for all tapes in the 2420 and 3420 groups and for some tapes in the 2401 groups.

h. Tape speed ranges from 75 ips for the 2401-5 group and 3420-3 group to 200 ips for the 3420-7 group.

i. As a function of the tape speed the transfer rate varies from 31.3 Kbytes per second to 320 Kbytes per second.

The independent manufacturers match or better the IBM 2401, 2420 and 3420 tape characteristics. In addition, advances made in the drive mechanisms incorporated into some plug-to-plug compatible transports result in higher reliability and lower tape wear. Other extra features such as autothreading, dual-density, and faster rewind result in performance increases. Prices for these devices are reduced from 1070 to 50% over IBM. Further details with respect to performance and cost information can be found in Ref. 23.

4. Future Possibilities

Storage Technology Corporation has introduced a series of magnetic tape systems, compatible with IBM computer systems, that can read and write standard magnetic tape at a recording density of 3,200 bpi. The new density

is offered by STC in the 3500/3800 Magnetic Tape Subsystem. The 3500 drive is basically the same unit as preceding versions and may be field upgraded to 3,200 bpi capability. The 3500 drive, according to STC, approaches the limits of technology as far as currently available media are concerned. Any further advance in recording density will probably have to be accomplished by changes in the media or basic recording techniques.

B. DRUMS

Instead of disk units for large on-line storage, UNIVAC uses large drums. Also the only large storage devices for UNIVAC equipment is the drum and thus replacements for large storage devices must be UNIVAC drum compatible.

The UNIVAC FASTRAND Mass Storage Subsystem provides the 1108 Multi-Processor System with an expandable random access external storage facility. Storage capacity ranges from 1,059,028,992 6-bit characters for the maximum subsystem configuration down to 132,120,576 6-bit characters for the minimum configuration. A FASTRAND Mass Storage Subsystem consists of one to eight FASTRAND II Mass Storage units plus a FASTRAND Control Unit. The FASTRAND II Mass Storage Unit consists of two drums, each rotating at 880 RPM. Combining this speed with a linear density of 1000 bits per inch yields a data transfer rate of approximately 157 thousand 6-bit characters per second. The FASTRAND II capacity is 132 million 6-bit characters recorded on 6,144 tracks on each drum. Each track is broken up into 64 sectors with 28 words per sector. The average time to access a sector is 92 milliseconds, with a maximum time of 156 milliseconds. This access time includes the time to position a read/write head over the desired track and the time for rotation of the drum so that the desired sector is under the read/write head.

The FASTRAND II Mass Storage Unit has a maximum capacity of 1.59 billion 6-bit characters and a minimum capacity of

198 million 6-bit characters with a data transfer rate of 222 thousand 6-bit characters per second due to a higher density recording, the only real distinguishing feature between the two FASTRAND devices. As a result, the access times for the FASTRAND III are identical with those of the FASTRAND II.

Three manufacturers, namely, Ampex, Data Products and California Computer Products (Calcomp), offer replacements for the UNIVAC FASTRAND drums. Ampex offers the AMPRAND II and the AMPRAND III; Data Products, the DP7010 and the DP7114; and Calcomp offers the 1144DS. All of these units are disk replacements that are plug compatible with the UNIVAC FASTRAND II or FASTRAND III, and offer significant performance and price advantages.

The AMPRAND II uses 5 disk drives to emulate a FASTRAND II, while the AMPRAND III uses a disk drives to emulate the FASTRAND III. Respective capacities are identical. Performance characteristics are favorable, with a transfer rate of 500 thousand characters per second, as well as an average access time of 44.5 milliseconds. These units offered by Ampex are their proven 2314 compatible disk drives, which have been demonstrated to be more reliable than the FASTRAND [Ref. 23].

The DP7010 has the same capacity as the FASTRAND II, while the DP7114 has a capacity greater than either FASTRAND drum with 310 million characters. Again, performance characteristics are better than FASTRAND's. The

transfer rates of the DP7010 and the DP7114 are 462 thousand and 314 thousand characters per second respectively. Average access times only show a slight improvement; 72 milliseconds for the DP7010 and 67 milliseconds for the DP7114. The DP7114 has been purchased by UNIVAC and will be offered as regular disk storage for UNIVAC systems.

For the Calcomp 1144DS, 3 and 4 disk drives emulate the FASTRAND II and III, respectively. Calcomp also does not offer an increase in capacity but does feature an average access time of 45 milliseconds with a range of 22.5 to 67.5 milliseconds. The Calcomp unit and the Ampex units are plug-to-plug compatible with the UNIVAC 400 and 1100 series systems. The Data Products units are listed as replacements implying possible software adjustments. For futher detail on performance and price information refer to Ref. 23.

C. DISC UNITS

1. Summary of Characteristics of Equipment Available

a. Number of Units Compatible With Each IBM Model Category

Model	Single Density	Dual Density	Higher Density
IBM 2311	17(7.25Mbytes)		
IBM 2314	17(29Mbytes)	11(58Mbytes)	4(116/232Mbytes)
IBM 3330			5(100Mbytes)

The classification of single, dual and higher density pertain to combinations of bits per inch and tracks per inch which provide the capacities shown in the above table.

b. Summary of the Characteristics of Each IBM Model Category

The existing IBM disc drives shown in Table II form the basis for comparing the compatible disc drives. Basically, plug compatibility implies that installing the new device does not require any changes in hardware or software and performance will not be degraded. A brief description of some of the less obvious specifications listed in the table follows:

DENSITY: BPI - bits per inch

TPI - tracks per inch

RECORDING TECHNIQUE: NRZ (non-return to zero) results in each recording of a change from a zero to a one or vice-versa to be accomplished by a full flux transition.

NO. OF CYLINDERS: Equivalent to the number of tracks on a disk surface.

FIXED HEAD: One read head per track; gives virtually instant track selection.

MOVABLE HEAD: One or more read assemblies, each accessing several tracks.

MIN/CONTR: Minimum capacity in MBYTES (10^6 - 8 bit bytes) for a controller, usually equivalent to one drive's capacity.

MAX/CONTR: Maximum capacity in MBYTES for a controller, maximum configuration of drives per controller.

MIN ACCESS TIME: The cylinder-to-cylinder access time; the time in milliseconds to move the read/write reads

from one cylinder to an adjacent cylinder.

AVE ACCESS TIME: Average time in milliseconds to move the read/write read from one cylinder to any other randomly selected cylinder.

MAX ACCESS TIME: The full stroke access time; the time in milliseconds to move the read/write heads from the innermost to the outermost cylinder.

AVE ROTATIONAL DELAY: One-half the rotation time in milliseconds, often referred to as the average latency time.

ROTATIONAL SPEED: Number of revolutions per minute of the disc.

TRANSFER RATE: The rate in KBYTES (10^3 bytes) per second at which data can be transferred to or from the disc drive, once the read/write reads are positioned over the correct cylinder and addressed record.

PURCHASE: Single unit putchase drive without maintenance.

RENTAL: Monthly unit rental with maintenance (single-shift) included.

MAINTENANCE: Monthly payment necessary to obtain single-shift (8 hours) maintenance of the purchased disc drive. This figure includes parts and labor.

Although several IBM 2311 compatible disk drives were located they were not high density and are not of interest in this thesis. Also, the single density IBM 2314 compatibles, which have 2000 BPI and 100 TPI are not

included for the same reason. The general performance characteristics of each high density compatibility class is shown in Table III. The general characteristics and difference between individual models will be discussed in the following sections.

TABLE II

EXISTING IBM DISC SYSTEMS

Identification	2311	2314	3330
Disc Pack #	1316	2316	3336
Controller #	2841	2314	3830
Technology			
Density - BPI	1000	2000	4040
- TPI	100	100	192
Recording Technique	NRZ	NRZ	
# of Cylinders	203	203	404
Removable or Fixed Pack	R	R	R
Movable or Fixed Head	M	M	M
Capacity			
Per Drive (MBYTES)	7.25	29	100
Per Cylinder (KBYTES)	36	145	247
Min/Contr. (MBYTES)	7.25	29	200
Max/Contr. (MBYTES)	58	233	800
Performance			
Ave. Access Time (MSEC)	75	60	30
Min. Access Time (MSEC)	25	25	10
Max. Access Time (MSEC)	130	130	55
Ave. Rotational Delay (MSEC)	12.5	12.5	8.4
Rotational Speed (RPM)	2400	2400	3600
Transfer Rate (KBYTE/SEC)	156	312	806

TABLE II

(Cont)

Cost - Disk Drive			
Purchase	21,030	20,490	51,940
Rental (with maint) ($/MON)	570	535	1,300
Maintenance ($/MON)	55	75	170
Cost - Controller			
Purchase	21,790	56,810	95,880
Rental (with maint) ($/MON)	525	1,480	2,400
Maintenance (1 shift) ($/MON)	56	60	145

TABLE III

GENERAL DESCRIPTION OF IBM COMPATIBLES

Identification	2314		3330
	Dual Density Replacements	Dual Density Replacements	Replacements
Technology			
Density - BPI	2,000		
- TPI	200		
Recording Technique	NRZ		
# of Cylinders	400		404
Removable or Fixed Pack	R	R	R
Movable or Fixed Head	M	M	M
Capacity			
Per Drive (MBYTES)	58	116	100
Per Cylinder (KBYTES)	145		247
Min/Contr. (MBYTES)	58	116	100
Max/Contr. (MBYTES)	466	1,800	800
Performance			
Ave. Access Time (MSEC)	35	55	30
Min. Access Time (MSEC)	10	12	
Max. Access Time (MSEC)	60		

TABLE III

(Cont)

Identification	2314 Dual Density Replacements	2314 Dual Density Replacements	3330 Replacements
Ave. Rotational Delay (MSEC)	12.5		8.3
Rotational Speed (RPM)	2,400		3,600
Transfer Rate (KBYTE/SEC)	312	234	
Cost			
Purchase (8 Drives + Contr.)	$190,000		$350,000
Rental with Maint. (Per month)	$ 4,725		$ 7,600
Maintenance (Per month)	$ 688		$ 1,500

2. Performance Summary

a. IBM 2314 Dual Density Replacements

A list of the companies and the models of the 2314 disc drive compatibles which are dual density is:

COMPANY	DRIVE	CONTROLLER
AMPEX	DS 324	
BASF SYSTEMS	214	1014
CALIFORNIA COMPUTER PRODUCTS	CD 22	CD 14
	CD 215	CD 1015
CENTURY DATA SYSTEMS	CDS 214	CDS 1014A
CONTROL DATA CORPORATION	23142	
HITACHI	H-85771-2	H85775
INFORMATION STORAGE SYSTEMS	ISS 715	
MARSHALL DATA SYSTEMS	M2900	M2800
MEMOREX	665	661
TELEX	5625	5650

As implied, all dual density IBM 2314 replacements have a capacity of 58 MBYTES per drive versus 29 MBYTES for the 2314. This doubling of capacity is achieved in a number of ways which will be discussed later in section 5. Basically, dual density is achieved by doubling the number of tracks (or cylinders) and consequently the number of tracks per inch. All of the above listed drives are like this except Memorex which doubles the bits per inch instead.

As a result, the Memorex drive has a rotational speed of 1200 RPM in order to maintain the compatible data transfer rate of 312,000 BYTES/SEC. The other drives have a rotational speed of 2400 RPM for the same transfer rate. The average access time for the 2314 replacement ranges from 29 milliseconds (MSEC) to 60 MSEC; the minimum access time ranges from 7 MSEC to 12 MSEC; the maximum access time ranges from 55 MSEC to 65 MSEC. The average rotational delay is 12.5 MSEC for all drives except Memorex which has an average rotational delay of 25 MSEC.

The IBM 2314 replacements all have movable read mechanisms and removable packs. Most units are able to use the IBM 2316 pack. All the above drives are IBM plug-to-plug compatible except for the Information Storage Systems's (ISS), Telex and Ampex drives. The ISS 715 is engineered for practical integration into existing systems with minimum controller and programming changes. This apparently means that ISS supplies the necessary modification at some extra charges (this may be wavered under a contract). Telex supplies DOS and OS modifications at no extra charge. Ampex offers compatibility with 4 drives; however, 8 drives require software changes (apparently supplied by Ampex at some extra charge.

b. Higher Density IBM 2314 Replacements

COMPANY	DRIVE	CONTROLLER
Century Data Systems	CDS 215	
Data Products	314	7361

COMPANY	DRIVE	CONTROLLER
Data Products	7318	7360/7361
Hitachi	H85771-4	H85775

The higher density 2314 replacements recorded have a capacity per drive of 116 MBYTES, except for the Data Products 314 which has a capacity of 232 MBYTES per drive. The capacity per controller reaches 1.8 billion bytes. The CDS 215 has a removable pack and a movable read mechanism, while the Data Products 314 has a fixed pack.

Hitachi and Century Data Systems offer plug-to plug compatibility with IBM 360 and 370 systems, while Data Products list their higher density drives as 2314 replacements suggesting possible software modifications.

The IBM 3330, and its compatible disk drives, are also a possible replacement for the 2314 on Systems 360/85-195 and 370.

Table IV provides a quick reference to some of the IBM 2314 replacement specifications.

TABLE IV

IBM 2314 REPLACEMENT SPECIFICATIONS

Density	Single	Dual		Higher			
Capacity/drive (Mbytes)	29	58		116			232
Capacity/cyl (Kby (Kbytes)	145	145	280	145	280	unknown	312
No. cylinders	203	406	203	812	406	-	745
RPM	2400	2400	1200	2400	2400	-	600*
ave rotational delay (MS)	12.5	12.5	25	12.5	12.5	-	50*
bpi	2000	2000	4000	2000	2200	unknown	6000*
No. Devices	17	10	1	1	1	1	1
Company	-	-	Memo-rex	Data Products	Hitachi	Century Data 215	Data Products
Device No.	-	-	-	7318	H-85771-4	-	314

* These values are estimates. They were calculated on the assumptions that the disk diameters are the same as 2316 disk packs; the density is higher than 4000 bpi; and the speed is less than 1200 rpm and an integral fraction of 3600 rpm. The first choice for the speed that satisfies these conditions is 600 rpm. Thus, using the fact that 2400 rpm and 2000 bpi produces a transfer rate of 312 Kbytes/sec, and that the Data Products transfer rate is 234 Kbytes/sec, the density was calculated as

$$\frac{234 \text{ Kbytes/sec}}{312 \text{ Kbytes/sec}} \times \frac{2400 \text{ rpm}}{600 \text{ rpm}} \times 2000 \text{ bpi} = 6000 \text{ bpi}$$

It is believed the Data Products Corp. does not advertise the bit density or the rotational speed because it would then be easy to calculate the high rotational delay.

c. IBM 3330 Replacements

COMPANY	DRIVE	CONTROLLER
Century Data Systems	CDS 230	CDC 1030
Control Data Corporation	9750	
Memorex	670	671
Potter	DD 4330	DC 5830
Telex	6330	

Caelus CMCX 3330 DISC PACK

The IBM 3330 and its replacements feature 100 MBYTES capacity per drive, reaching a maximum of 800 MBYTES per controller (8 drives). The CDC 1030 controller can operate 2, 4, 6 or 8 drives. The Potter DD 4330 is a 2-drive unit, using 4 DD 4330's for a complete system. Memorex allows further flexibility in that its 671 controller can have a configuration of from 1 to 8 drives. All the models can use the IBM 3336 disc pack, except for the Memorex 670 drive which uses its own MARK TEN disc pack. Consequently, the packs are all removable and the drives all have a movable read head mechanism.

The average access time for the IBM 330 replacement ranges from 25 to 30 MSEC. The data transfer rate is 806,000 BYTES/SEC. All of the models feature plug-to-plug compatibility with IBM 360 and 370 systems, except for the CDC 9750 which might need software modifications. The earliest available 3330 replacement model is the CDS 230, scheduled for delivery in March 1972.

As an added note, Caelus offers the CMCX 3330 disc pack which is 100 percent compatible with the IBM 3336 disc pack. The CMCX 3330 has a storage capacity of 100 MBYTES. Each disk surface within the pack can contain up to 404 primary tracks with an additional seven tracks available as alternatives. Track density is approximately 200 tracks per inch; bit density is a maximum of 4040 bits per inch.

d. Access Time Summary

The minimum, average and maximum access times are summarized as a function of capacity per controller for all classes of IBM 2314 replacements (replacement of 2314's by 3330's is restricted to system 360/85 - 195 and system 370) in Figure 1. This information is plotted for all devices from all suppliers but in some cases only average access times were available. The reduction obtained in average access time with 2314 replacements is shown in Figure 1. This is in addition to the added capacity. The higher density 2314 replacements, due to their higher capacity, have a higher average access time than the IBM 2314 dual density replacements. Also of interest is the similarity between the IBM 3330 and its replacements.

3. Cost Summary

a. Purchase

The 2314 dual density replacement price is about $15,000 per drive versus $20,490 per IBM 2314 drive. Where the independent manufacturer provides a controller, its price is about $54,000 versus $56,810 for the IBM 2314

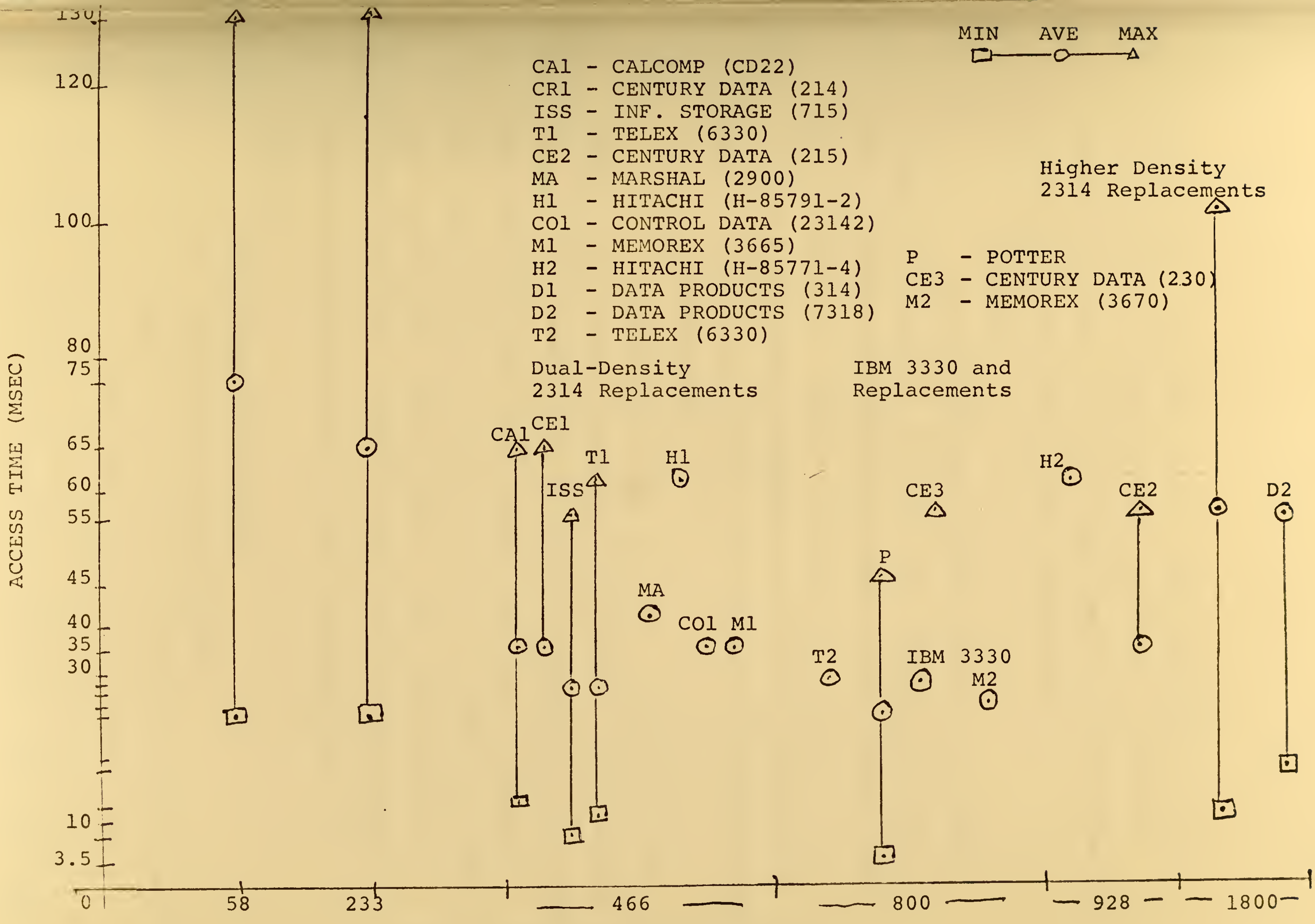


FIGURE 1 ACCESS TIME SUMMARY

controller. The higher density 2314 replacement which features the 116 MBYTE capacity per drive is quoted at $26,000 per drive. The 3330 replacements are advertised at a savings of from 8 to 18% over the IBM 3330

b. Rent

The rental prices quoted include a one shift (8 hour) maintenance. The 2314 dual density replacement drive rents for about $525 per month versus $535 per month for the IBM 2314. Where controllers are offered, the rent is $1,210 per month as opposed to $1,480 for drives and a spare, the 2314 replacements rent for about $4,725 per month.

c. Maintenance

Maintenance costs are for a one shift per day monthly rate for any purchased disc system. The 2314 dual density replacements have an average maintenance cost of $78 per month for a drive and $64 per month for a controller. The charge is $75 per month for a drive and $60 per month for a controller. Thus, there is very little saving in maintenance cost. However, there can be a considerable saving in purchase price or rental by using compatible devices.

4. Performance/Cost Summary

a. Purchase Cost Versus Capacity

Figure 2 is a plot of purchase cost for 8 drives and a controller versus the capacity of 8 drives over all models. As would be expected the cost generally goes up as the capacity is increased. In the case of the 2314 dual

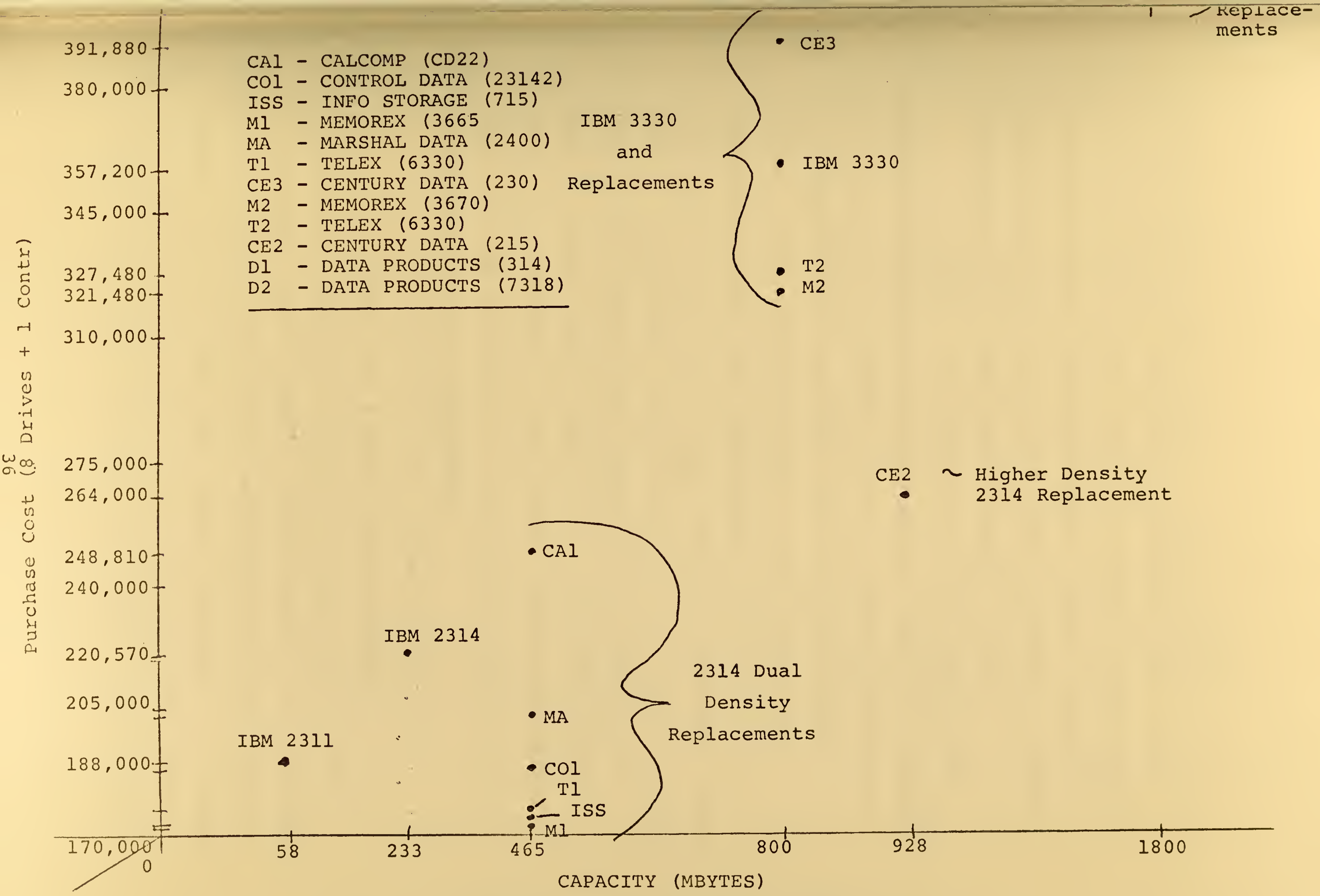


FIGURE 2 COST SUMMARY FOR DISKS

density replacements, however, a double capacity is obtained for the same price. Century Data Systems offers a drive with four times the 2314 capacity at about the same price as the double density 2314 replacements. Again, it can be seen that the IBM 3330 does not differ appreciably from its replacements in the cost versus capacity category.

Figure 3 was developed to get a better cost/capacity correlation among all models. Figure 3 is a plot of the purchase cost/MBYTE versus the capacity for 8 drives. It is obvious from the figure that for large capacity systems, a cost savings of three to five times can be achieved by buying 2314 replacements. Considering the wide range of capacities of the different replacement groups, there is surprisingly little variation in the cost per MBYTE. Note the high capacity and competitive cost/MBYTE of the IBM 2314 higher density replacements, especially Century Data 215, as compared to the IBM 3330 and its replacements. Again, the IBM 3330 does not significantly differ in price-performance from its replacements.

b. Purchase Cost Versus Average Access Time

Figure 4 is a plot of the purchase cost of 8 drives and 1 controller versus the average access time in milliseconds over all models. Evident again is the advantage of the IBM 2314 dual density replacements over the IBM 2314. Based on cost, the 2314 dual density replacements are better than the 3330 replacements for the same approximate average access time of 30 milliseconds. The IBM 2314 higher density

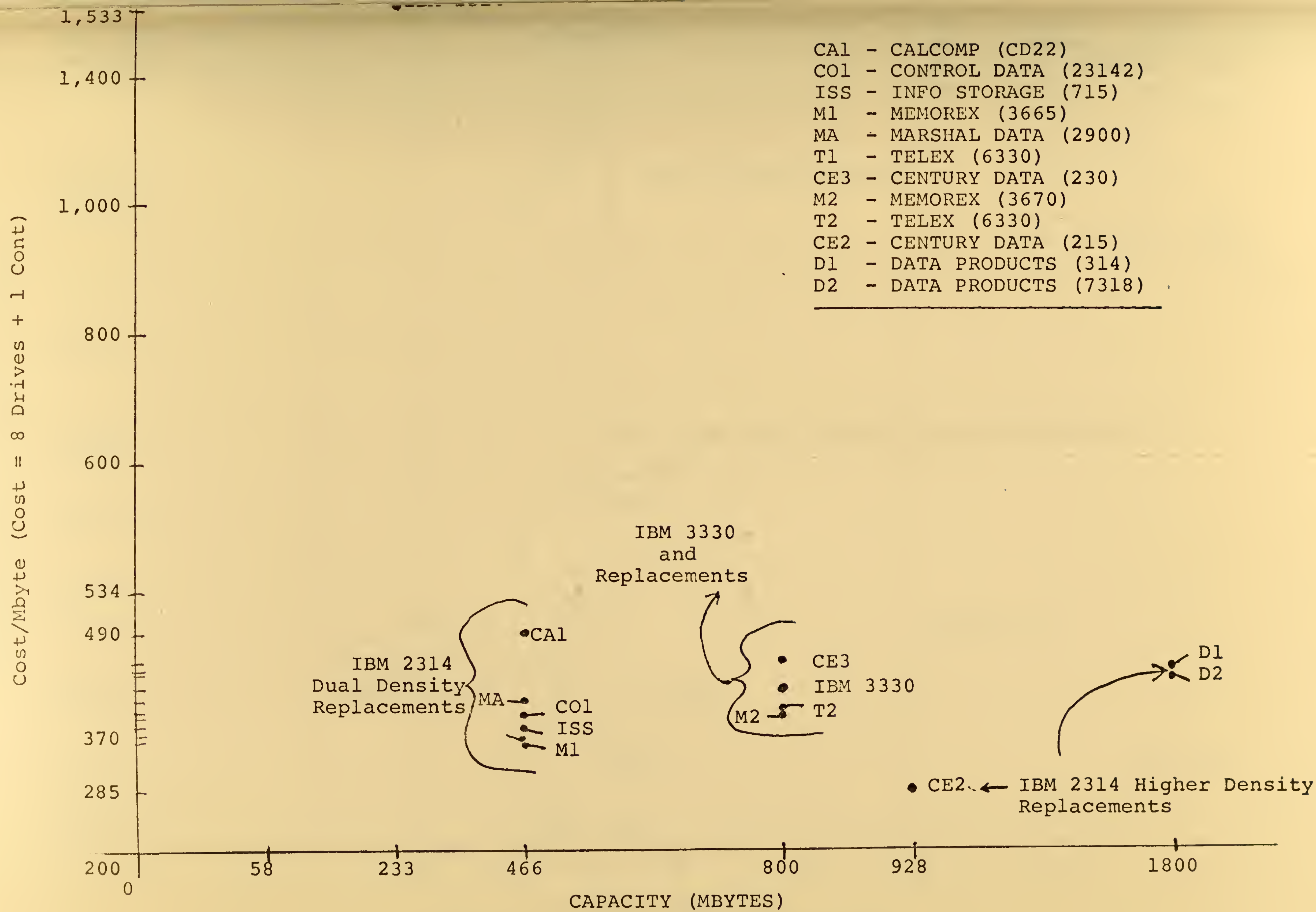


FIGURE 3 COST/MBYTE VS CAPACITY

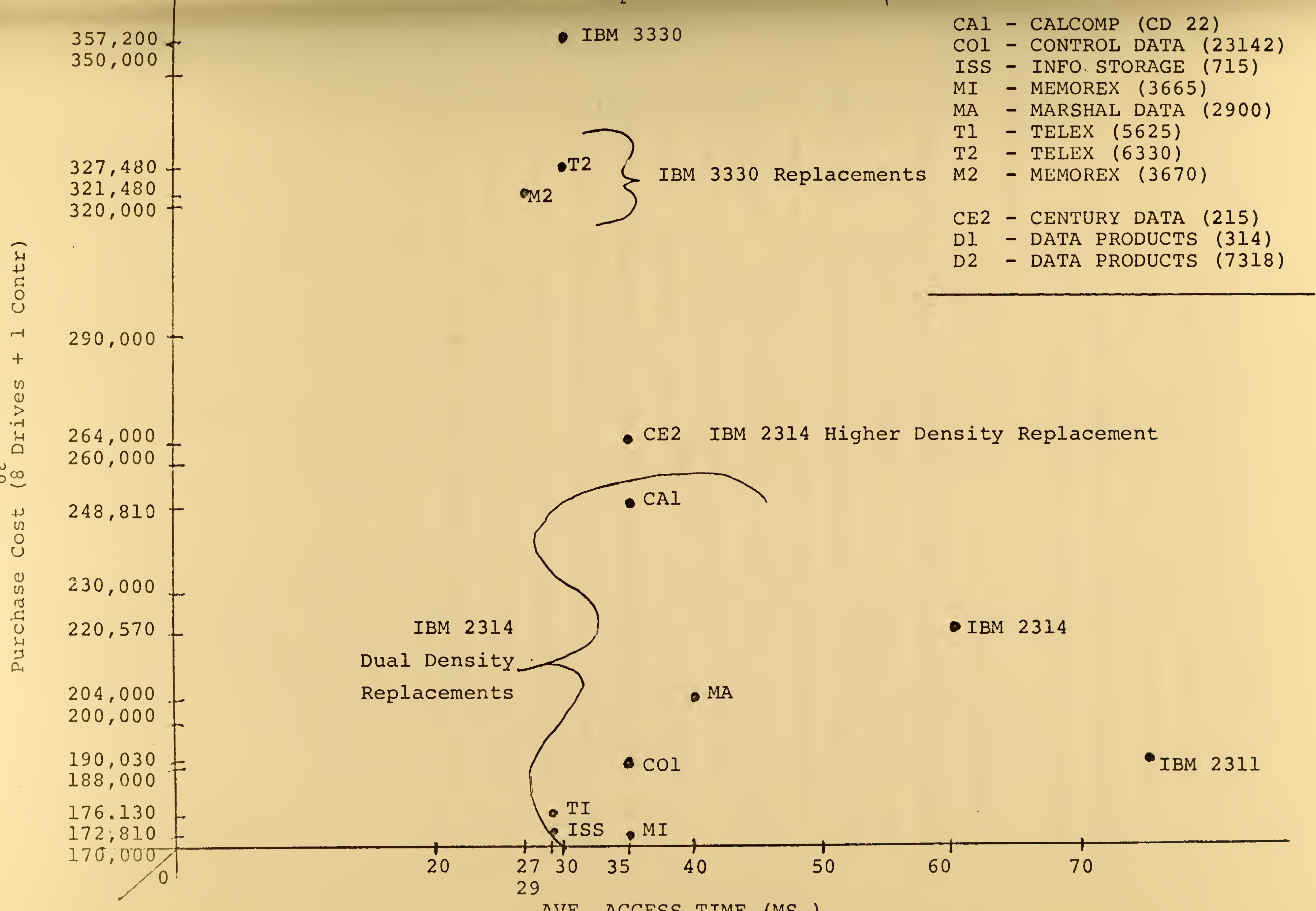


FIGURE 4 COST VS AVERAGE ACCESS TIME

replacements do not compare favorably due to their high cost and relatively high access time. The higher density Century Data Systems 215 has better price-performance than the two higher density replacements offered by Data Products. The IBM 3330 and its replacements differ slightly in price-performance.

Figure 5 is a plot of the purchase cost/MBYTE versus average access time in milliseconds over all models. From the figure, it is obvious that an access time of about half that of IBM 2314 can be obtained with the replacements, as well as the three to five time cost saving mentioned previously. It is interesting to note the cluster of points between 27 and 40 milliseconds and between 370 and 440 dollars per MBYTE. Obviously, there is no appreciable difference between the IBM 2314 replacements and the IBM 3330 and its replacements, when considering these parameters. Of special interest again is the favorable performance of the Century Data Systems 215, which is about one-fifth the cost/capacity and has about one-half the access time of the IBM 2314.

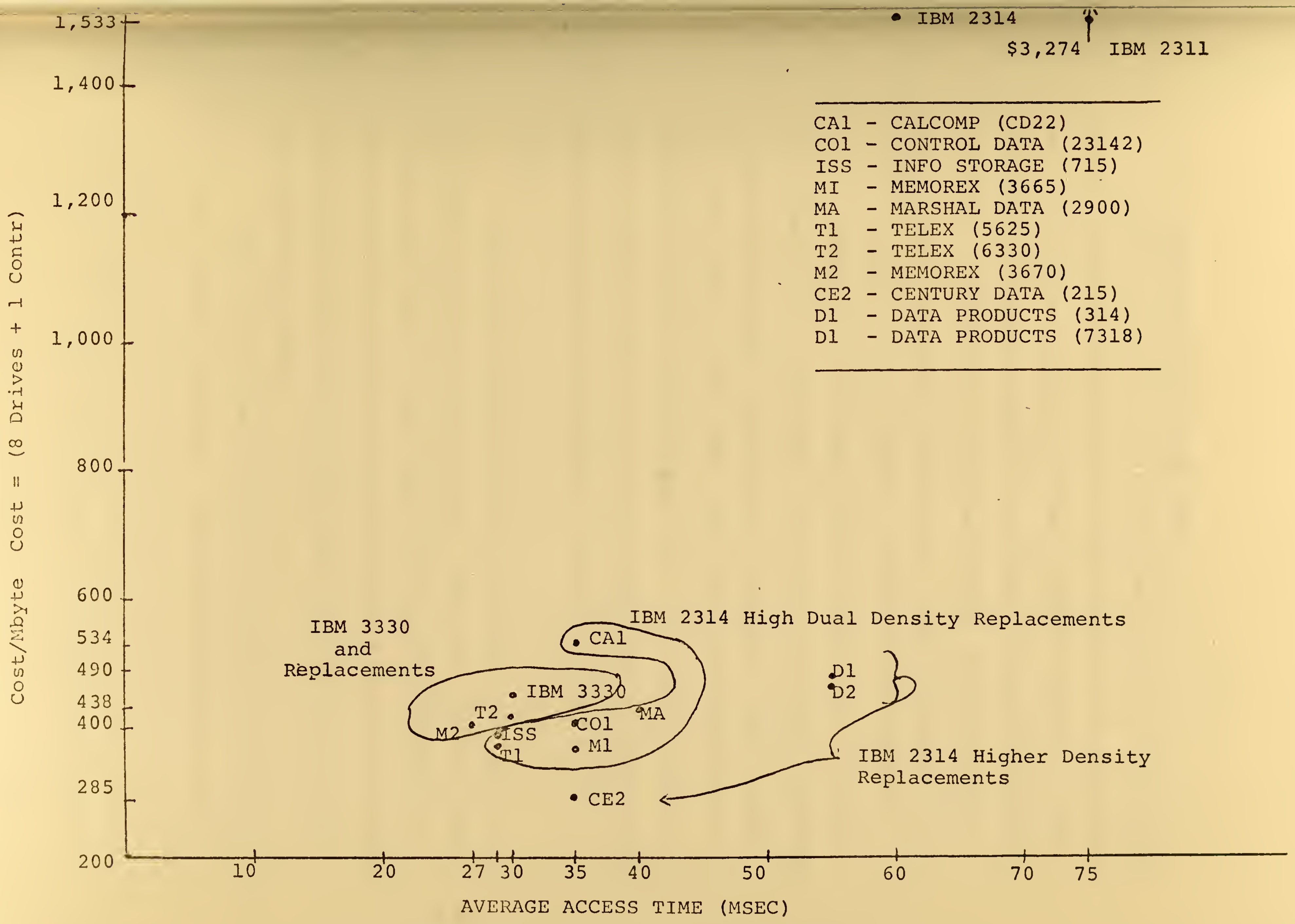


FIGURE 5 COST/MBYTE VS ACCESS TIME

5. Double Density Techniques

The ability of a 2316 disk pack to store 58 million bytes instead of 29 million has been referred to as double density, double capacity and dual-cylinder density. This increase in storage requires a physical change in the data recording techniques. Of prime concern to the double density environment is the ability to execute existing system and application software without modification.

There are five basic physical methods that double the capacity of a 2316 disk. The first technique, employed in the Memorex 3665, reduces the rotational speed of the disk from 2400 to 1200 RPM. This reduction results in doubling the bits recorded per inch. The major problem of this method is that the average latency time is doubled to 25 milliseconds, thus adding to the access time within a track.

The second method, which is not used by any of the previously mentioned disk drives, does not alter the rotational speed but it does double the recording density. This method increases the data transfer rate to 624 thousand 8-bit bytes per second, which limits such devices to the IBM 360/65 and above.

The third method doubles the number of tracks per inch, resulting in 406 cylinders. The data management and I/O routines in the system software must be modified to use the space available; i.e., space availability is determined by examining the VTOC (Volume Table of Contents) and using a

base of 203 cylinders for necessary calculations. Other modifications are required to access methods and I/O supervision. The Telex 6330 uses this method.

The fourth method, employed by the Control Data 23142 and the Marshal Data Systems 2900, also uses 406 cylinders, split into two logical halves. Each logical unit is then addressed as two separate disk packs, implying no software modifications are necessary for implementation. Upon studying a seek timing graph, however, this method appears less attractive because of the time required to traverse 200 cylinders. Around 80% of the time is expended in traversing the first 200 cylinders, especially if the VTOC remains on cylinders 0 of both units. This time can be reduced if the VTOC of the first logical unit is on cylinder 199 and the VTOC of the second logical unit is on its cylinder 0. The effect of having nonstandard VTOC's must now be evaluated to determine the depth of system and operating repercussions.

The Calcomp CD22 uses the fifth method which also employs 406 cylinders to effectively double the recording density. Again, the 406 cylinders are divided into two logical units, but now the cylinders are interleaved rather than split into two contiguous segments. By interleaving the cylinders, data sets can be physically placed for optimum access time. If the centers of activity of two data sets are the same, then this method will produce equal or better access time compared to two separate disk drives;

and very little, if any, system degradation will occur. The fifth method is the only one that can read disk packs that were written on single density drives. This is a very valuable feature for file conversion and provides some compatibility.

Some areas that will be enhanced by the double density are as follows:

a. Sequential or indexed sequential multi-volumed files.

b. Large data bases with a low activity rate.

c. Large data bases with a high activity rate and a noncritical response time.

d. Applications requiring large data bases online.

e. Applications not generating many over-lapped seeks.

f. Applications requiring few pack mounts or dismounts.

III. MASS STORAGE SYSTEMS OR DEVICES

A. DEFINITION

A Mass Storage System could be defined as a system with a capacity greater than a billion bits, but in the literature, a more popular mass storage capacity is a trillion bits. A trillion bits may sound like a fairly reasonable amount of data storage, but it is almost incomprehensible when one realizes it is equivalent to 2,999 reels of standard 1600 bpi tapes, or 3,500 2314 disk packs, or 1,000 3300 disk packs.

Possible uses of mass memory are:

1. A cheaper extension of main memory, where long access times are acceptable.

2. For residence of the control programs and compilers. A read only memory would be sufficient in this case.

3. For storage of an on-line data base, possibly in some sort of storage hierachy scheme.

Manufacturers with currently available mass storage devices envision number 3 as the most likely use.

Mass storage systems could be subdivided into high density mass storage and large surface mass storage. The latter dependent more on mechanical control, thus conceivably more prone to failure, also having longer access times. Naturally, a clear distinction does not exist as most devices are dependent to some degree on both mechanics, but a

spectrum of mass storage systems does exist. Another point is that not all mass storage devices on the market or in the laboratories are complete systems. Some manufacturers such as International Video supply only a storage device and leave interfacing and data transmission to the user.

B. DIFFERENT APPROACHES

Basically, there are five techniques employed in achieving high density recording. They are as follows:

1. Video Magnetic Recording

To date, video magnetic recording techniques have demonstrated packing densities of approximately 1 million bits per square inch on video tapes. Thus, for a trillion bits of data a surface area of 1 million square inches is required, implying heavy dependence on mechanical motion to control this large recording area. As a result, when video tapes are used as the recording medium, speeds of about 1 thousand inches per second are used to move the tape during searching operations.

2. Magnetic Recording

Using magnetic tape as a recording medium, densities up to 8 thousand bits per inch per track and 16 tracks per inch have been demonstrated. This implies a somewhat larger surface area than for video recording and is also very dependent on mechanical motion. Recording surface for a trillion bits memory must be about 4 million square inches. Also, as the linear density increases, the distance from

the head to tape must decrease, with possible contact recording being necessary. Higher bit and track densities necessitate smaller bit areas, thus implying smaller amounts of magnetic material to induce voltages in reading heads. Also, finer track spacings imply very difficult dimensional tolerance problems in the head positioning mechanisms.

3. Optical Recording and Readout

The high packing density potential of optical memories is the result of a basic principle of optics which states that an optical beam can be focused to a diffraction - limited spot whose diameter is approximately equal to the wavelength of the light. For visible light having a wavelength of approximately 0.5 microns (10^{-6} meter) the potential density of resolvable focused spots is in excess of 1 billion per square inch. In a memory, the spots must be seperated by at least one or two beam diameters to uniquely define a bit, so that densities of more than 100 million bits per square inch can be expected. For this case, a trillion bit memory would only require 10,000 square inches of recording surface, which is a recording area equivalent to eight 2314 disk packs. The basic system of an optical memory will include a beam source, a beam control device, a memory medium, a beam deflector, focusing and pivoting optics, and a detector. The light source used in such a system is the laser currently used in a non-erasable mode.

4. <u>Holographic Recording</u>

When an information carrying optical beam, or signal beam, is made to intersect with a coherent optical reference beam at a pre-selected angle, which is typically between 5 and 80 degrees, then a fine-structure interference pattern results, which, when recorded forms the "hologram". A page of text could be electronically or optically composed and introduced onto the information carrying beam that propagates through an X - Y deflection system and impinges on the hologram, a data storage array. The coherent optical reference beam for writing the hologram intersects the information carrying beam and thus holographically "writes" the page of text on the data storage array. To "read-out" a desired page from the holographic data storage array, an optical reference beam for reading would be directed onto the hologram and an array of photodetectors would be used to read the information from the reconstructed page of text.

In a holographic optical memory, a page of data consisting of an array of approximately 10^4 bits is stored in a hologram having a diameter on the order of 1 millimeter. Acoustic-optic deflectors capable of two-dimensional deflection to an array of 64 X 64 holograms with an access time approaching 1 micro-second are presently feasible, so that approximately 4×10^7 bits of data are available with an access time of approximately 1 micro-second. About 100 square cm. of surface area is required for the above holographic array, for a recording density of 1.5 million bits per square inch.

To achieve more than 10^8 bits will require mechanical motion.

5. Electron Beam Recording

The theoretical limit to spot size for an electron beam store is of the order of 10^{-2} microns. This represents a potential gain over optical recording of 3 - orders of magnitude in recording density and would permit, in principle, information densities of the order of 10^{12} bits per square inch. In principle, electron beam targets can be made by using a high resolution form of electron beam machining to cut holes in a target, similar to the technique using a laser beam. The presence or absence of these holes can be detected with a low intensity beam. Such a subsystem would display the same characteristics as the analogous optical storage system, permitting incremental recording, unlimited readout, but no erasure.

C. EXAMPLE SYSTEMS

1. Video Magnetic Recording

a. The Ampex Terabit Memory (TBM) System uses the video technique of rotating heads and transverse recording to store large volumes of digital data on a very few reels of magnetic video tape. This system provided random access capability through extremely high speed searching (1,100 inches per second) in combination with a reusable, update in place, magnetic storage media. The Terabit Memory is being developed jointly by the Department of Defense and the Ampex Corporation, under a task beginning in 1966.

In a full configuration, the TBM consists of 64 tape drives on 32 tape transports. Each 3,750 foot tape averages 45,000 blocks of data, each block containing 10^6 bits of data for a total capacity of 45×10^9 bits per tape and approximately 3×10^{12} bits per system. Data is recorded in the transverse mode, i.e., across the tape using rotating heads, at a linear density of 7500 bits per inch, on standard 2-inch wide video tape. Three longitudinal tracks, the address, tally and control tracks are also provided. The address track holds the address of the block, the lowest level of addressing in TBM. The tally track is for the user to record auxiliary information, such as number of accesses to each data block, illegal addresses or addresses in which tape defects occurred, while the control track is for system use. During high speed search, only the control, tally, and address tracks are read and the rotating transverse head is not in contact with the tape, thus significantly reducing tape wear during the search operation. If the tape is returned to mid-reel after a read or write process, then the average access time to a block is 10 seconds and the maximum is 22 seconds. However, if a random start point per reel is used, the average block access time is 15 seconds and the maximum - 44 seconds, the time to search a tape. The transfer rate is 750×10^3 (8-bit) bytes per second per channel, or effectively 4.5 million bytes per second for 6 channels. TBM has 100% redundant recording with an intended error rate of

1 in 2 X 10^{10} bits.

Functionally, the TBM System can be divided into two parts: The Memory Section and the Control Section. The Memory Section consists of Transport Modules, Transport Drivers, and Data Channel Units. A Transport Module contains two tape transports and the switching elements necessary to connect the tape transports to Transport drives. The tape transports have all the mechanical elements necessary to move tape but only a bare minimum of electronic components. The number of transport modules in a system can vary from 1 to 32, each module having a capacity of about 10^{11} bits.

The Transport Driver contains a mini-computer (NOVA) and the power, servo and control electronics necessary to operate a tape transport. As directed by the TBM System Control Processor, the mini-computer controls the transport to which it is connected during search and in addition, controls a read or a write channel during data transfer. It also monitors transport and Data Channel and reports I/0 completion with status to the TBM System Control Procedure. The number of Transport Drivers determines the number of tape transports which can be in operation simultaneously and is typically one for a minimum system of two tape drives and six for a maximum System.

The Data Channel contains all the electronics necessary to transfer data. The throughput of the system is determined by the number of Data Channel Modules. Each Data Channel Module has a read and write channel which can

be operated simultaneously, each at a rate of 6 X 10^6 bits per second. A maximum of six Data Channel Modules can be implemented in a TBM system, providing 12 read/write channels. Any combination of six channels can be operated simultaneously, thus providing a maximum system throughput of 36 X 10^6 bits per second.

The Control Section consists of a special purpose computer, called the System Control Processor (SCP), interface core buffers, and channel control hardware. The number of buffers as well as the number of TBM data channels is determined by the throughput requirements of each installation. Standard I/O devices may be attached to the SCP. Data transfer request are, in general, initiated by host CPU's. These messages are automatically interpreted by the SCP. The SCP allocates the appropriate resources, i.e., the necessary number of Transport Drivers, transports, R/W channels and interface buffers. In response to a READ request, data is retrieved from the TBM Memory Section and made available to the host CPU in interface core buffers. For WRITE operations, the SCP merely dedicates interface buffers, enabling immediate data transfer from a host CPU.

b. International Video Corporation markets the High Information Density (HID) Recorder, the IVC-1000. IVC uses a helical scan video recording technique on one inch tape, with 7,000 feet of tape per reel. Approximately 100 tracks are recorded across the tape at a linear density in excess of 11,000 bits per inch, resulting in an information density

exceeding one million bits per square inch of tape. In addition to the data recording, the recorder has a capability of four or more low-density tracks which are recorded longitudinally on the tape. A feature of the helical scan allows these longitudinal tracks to be recorded on tape first, then overwriting the longitudinal tracks with the transverse data tracks. This overwriting process is theoretically possible if the wavelengths involved on the address tracks are different by an order of magnitude from those on the data track, and if the data track's longest wavelength to be recorded does not fully penetrate the oxide coating. In the HID recorder, the address track information is recorded longitudinally at a digital density of approximately 280 bits per inch, which produces a shortest fundamental wavelength on tape of 3.3 mils. The data is recorded at 11,000 bits per inch, which produces a maximum wavelength on tape of 364 micro-inches. In actual practice, a lower error rate is achieved when the longitudinal tracks are recorded along the edge of the tape.

The recorder searches bidirectionally at a longitudinal speed of 400 inches per second which corresponds to a data search rate of 4×10^8 bits per second. The lowest addressable level is a track. Within a track are 1.2×10^5 bits of raw data, implying any blocking of data within a track is user implemented. The average time to access a random track is 70 seconds, with a maximum time of 210 seconds. Data is then transferred at a rate of 8×10^6

bits per second. READ/WRITE operations take place at a speed of 6.91 inches per second longitudinally. From a STOP position it takes 1.7 seconds to reach a search speed of 400 inches per second. As the read head approaches the desired track, the tape begins decelerating and takes 2.7 seconds to stop at the desired track. It then takes .6 seconds to reach a speed of 6.91 inches per second necessary for READ/WRITE operations and to establish synchronization.

The IVC-1000 is cartridge loaded and self-threading. Rewind time for the 7,000 foot reel is less than 3.5 minutes. The raw data error rate is less than one in 10^8 bits.

Although IVC and Ampex use different recording mechanisms, there are many similarities between the two systems. Both record at density of about one million bit per square inch on magnetic tape, have transfer rates of six and eight million bps and the same tape capacity of 45 billion bits (assuming the same redundancy). The major difference is that IVC markets only a recorder while Ampex markets a system. Also software houses such as Scientific Data Corporation and Texas Instruments may market the IVC recorder with the necessary software.

2. Magnetic Recording

Grumman Data Systems Corporation in Garden City, New York have developed a high density magnetic storage device called MASSTAPE. As indicated, Masstape is based on magnetically recording data on a 1/2 inch wide tape at a linear

density of 8,000 bits per inch on 16 tracks. This magnetic instrumentation tape is housed in a cartridge containing 260 feet of tape. The tape within a cartridge, when idle, is positioned at the midpoint allowing each track to be divided into two files, one on each side of the midpoint, allowing for 32 half-track files per cartridge. These half-track files, being the lowest addressable level, have a capacity of approximately 11.5 million bits. Tape speed is 150 inches per second.

The physical organization of the system is as follows. Eleven cartridges are contained in one Masstape pack. Four packs make up a drive in carousel form; each drive having its own read/write station. Within one storage unit, the largest physical unit, there are eight drives for a unit capacity of 125 billion bits. Each storage unit subsequently has eight read/write stations, but only four can be operating simultaneously. Up to eight storage units can be combined for a total system capacity of one trillion bits of data.

Any half-track file can be accessed in .6 seconds, the time necessary to rotate the carousel and position the cartridge. Average access to a single record is six seconds, with a maximum of 11 seconds. This search for a record must take place external to the storage unit, probably in a buffer unit which has a half-track file capacity and is controlled by a system mini-computer. When additional simultaneous accesses are required, buffer units are added to provide up to 32 simultaneous accesses. Trasnfers are

made on up to 16 computer interface channels. Data is transferred at 1.2 million bits per read/write station which implies an effective transfer rate of 19.2 million bits per second can occur.

There is one controller for the system which can handle from one to eight storage untis. The error rate for Masstape of 1 in 10^{9} bits is a system objective.

3. Optical Recording With a Laser

Precision Instruments offer a Laser Mass Memory System, the UNICON 690-212, which stores large static or semi-static data records on a permanent medium. The UNICON 690-212 is a device which uses a precisely focused laser beam to vaporize (burn) minute holes (approximately four by three micrometers) in the metallic surface of the data strip. The laser is modulated so that it is turned on to burn a hole for writing a 1 and turned off for a 0. In vaporizing bits, burn time is approximately 100 nanoseconds (10^{9} second) within a bit-cell time of 200 nanoseconds. During this writing process, light is reflected from the data strip, and this return beam is monitored in real time to provide a read-while-write data verification capability. When reading data, the incident laser light is reduced in power to avoid burning holes in the metallic surface, and then the reflected light is monitored to read whether a 1 or 0 is recorded.

The recording medium of the UNICON is a 31.25 inch by 4.75 inch strip, consisting of a thin metallic coating on a polyester base. Of this strip, 31 inches X 3.5 inches

is used for data recording. There are approximately 11,440 tracks recorded longitudinally down the strip for a strip capacity of 1.6 billion bits of data. There are 25 strips per pack and 18 packs per carousel for a total system on-line capacity of 0.7×10^{12} bits. One carousel exists per system and is horizontally rotated between two read/write units.

The UNICON consists of two basic units: a Laser Recorder Unit which performs the write/read functions and the physical retrieval of data strips from the on-line file, and a Recorder Control Unit which interfaces with the host computer and serves as the memory system controller.

The Laser Recorder Unit is composed of two read/write units, each of which has an independent simultaneous read/write capability. It is between these two units, that the carousel is rotated so as to load any selected strip for a read/write operation. The elements of the read/record unit are:

(1) a 10 inch diameter rotatable drum which operates at a speed of 1510 revolutions per minute. The drum provides for precise location and positioning of a data strip. The average rotational delay of the drum is 20 milliseconds.

(2) a load/unload mechanism, for transfer of data strips between the carousel unit and the surface of the strip drum.

(3) track-selection carriage unit, which supports an optical head incorporating a mirror galvanometer and an objective lens, which can direct a laser light beam onto any selected track region of a data strip.

In operation of the Laser Recorder Unit (LRU); to load a new data strip, the following take place:

(1) the carousel is positioned under the load/unload station to receive the strip presently mounted on the rotating drum.

(2) the drum is decelerated to stop at a particular point to unload the presently mounted strip into the carousel.

(3) the presently mounted strip is unloaded.

(4) the carousel is then rotated to bring the desired strip to the load/unload station.

(5) the drum is accelerated slowly as it loads the strip and then more rapidly until it reaches 1510 RPM.

These five steps occur in less than 10 seconds, and the procedure could have been directed to either read/record unit. Control now passes to the track-selection carriage unit which moves logitudinally down the drum (across the tracks). When it is positioned approximately over the desired track, the searching of the track is accomplished by the track moving under the optical head at 1510 RPM. Given that it takes 150 milliseconds to access a record once the strip is loaded, and that the drum has an average latency time of 20 milliseconds, then it can be deduced that it takes an average of 130 milliseconds

to access a given track. The time to get from track (i) to track (i + 1) is less that two milliseconds, while getting from track 1 to track 11,440 requires less than 400 milliseconds. Once a desired record is located, transfer of data then proceeds at 3.4 million bits per second.

The Recorder Control Unit (RCU) consists of a control computer, two word processors, two buffer core memories and associated priority controls, two read/write and error-control subsystems, and necessary I/O control units. The control computer is interfaced directly with the host computer and provides all system control functions. The word-processor programs are loaded and monitored by the control computer and provide the software interface between the data strip, buffer core memories and host computer.

Assuming that the host computer commands a record be written in a specific position on a specified file, the control computer loads the word processor with the write program, which includes the absolute track address and the physical record number of the record to be written. The work processor primes the memory address register of the buffer core memory, activates this memory and takes over control of the carriage and galvanometer, directing the laser beam to the proper position for the write operation - a requirement that briefly throws the work processor into the read mode to locate the proper point on the partly filled data strip where the write operation is to begin.

The RCU also established and maintains on each strip a directory of all data sets or files, and a directory of all available space. It performs all track allocation for data sets or files and all record address conversions from relative position to absolute track addresses. The error rate for the UNICON is objectively less than 1 in 10^8 bits.

4. Holographic Recording

The unique optical properties of a laser (namely, high intensity, highly collimated or directional, spatially, and temporally - coherent optical beam) and the holographic techniques available provides users with another mass memory alternative. RCA Laboratories in Princeton, New Jersey, has worked on an optical read/write memory system based on holographic storage. This optical read/write memory has two basic elements: a large central holographic memory that contains the system's total stored information; and an operating memory that at any time contains a small block or page of the main memory. The system operates on commands from a CPU, which orders the operating system to retrieve a block of data (a page) from the central holographic memory. The operating memory has a read/write capability: it can read the data stored in the holographic memory, or write new data into the memory. Data is transferred in pages to and from the operating memory via an optical path.

During the write cycle a laser beam first enters a two-dimensional deflector capable of shifting it to any position on a page. Since there are X rows and Y columns, the total number of page positions is X times Y. Each position represents an area on the storage medium containing one hologram. Thus, each hologram can be located by electrically deflecting the beam to that position. With interference between two coherent beams required to construct a hologram, the deflected beam next is split into two parts, a reference and an object beam. The reference beam is sent directly to the selected page location on the storage medium. The object beam impinges on a two-dimensional array of light modulaters called a page composer, before it reaches the same page location on the storage film. The page composer impresses the information to be stored on the beam. In this capacity it acts as a transducer, converting the electrical input data to spatial variations of intensity or phase of the object light beam. At the selected page location, the reference and object beams form an interference pattern to produce a hologram of the page, thus, finishing the write cycle.

To read the data, the selected page of the storage medium is illuminated with a reference beam alone, producing a real image. At this image plane, an array of photodetectors, whose spatial dimensions are the same as those of the page composer, converts the information into electrical signals. These signals in turn, set the states of flip-flops, one

for each photodetector cell. This integrated array, with its addressing circuitry, comprises the operating memory. Erasure of data is achieved by the application of an external magnetic field, which is large enough to saturate the film, thus removing the holographic magnetization pattern. The recording medium used in this system is a compound composed of manganese bismuth - a ferromagnetic material.

This device uses a mass storage principle, but, with a capacity of about 10^8 bits, it is not a mass storage device. It takes about 100 microseconds to access a page and, once that page is in the operating memory, it takes less than a microsecond to access a word from the loaded page. The recording density is 2.6 million bits per square inch, similar to other mass storage devices, but the recording area is only 15.5 square inches. This device is intended as a possible replacement for very fast drums or other direct access storage devices.

A good feature of holographic storage is that the information is redundantly stored in a hologram. If the hologram is partially obscurred due to dust particles or medium imperfections, the signal level on all of the photodetectors will be slightly reduced but all of the bits in the hologram can still be read correctly.

Besides RCA laboratories, Hitachi Ltd. and Fujitsu Ltd. are developing similar units.

5. Electron Beam Recording

The IBM 1360 Photo-Digital Mass Storage System, based on electron beam recording, is an on-line ultra-high capacity system with relatively slow access speeds (as compared to direct access storage devices) and a non-erasable recording medium. The system, as well as the other mass storage systems mentioned, was designed for applications where data requirements are too voluminous to justify storage on existing direct storage devices, but where activity ratios are too high for serial reading characteristics of magnetic tape.

Data is stored on a 1.38 X 2.75 - inch silver halide photographic film chip by using direct electron beam exposure. There are 32 frames per chip, 492 tracks per frame and 420 bits per track yielding a capacity of 6.6 million bits per chip. Thirty-two film chips are housed in a small plastic box (called a Cell) and transported pneumatically between storage modules and read/write stations. Off-line storage of cell containers is provided. In recording data double-frequency recording is used, that is, a "1" is encoded as an "opaque-transparent" mark on the film and a "0" as a "transparent-opaque" mark. The basic File Module stores 2250 cells for a capacity of 476 X 10^9 bits of data. Add-on modules can be attached, each providing storage for 4500 additional cells. Thus it takes on add-on module to make a 1.5 trillion bit system.

The major components of the system are the Control Processor, the Record/Develop Station, the Reader Station and the Data Controller. The System Control Processor serves as a digital process control computer with capability for error correction. Programs are stored and executed in the processor to directly control hardware functions in accordance with control and status messages received from the host computer. The Data Controller acts as the interface between the System Control Processor and the host computer. In the Tablon mass memory storage network, the Data Controller accumulates bursts of data from a PDP-10 computer until one full frame of data has been received. The Data Controller then initiates the Recorder and forwards the entire frame of data for writing. On reading, the Data Controller accepts data from the Reader Station and prepares them for transmission to the PDP-10.

The Record/Develop Station records the film chip with data passed from the Data Controller, one frame at a time, then completely and automatically develops, washes, and dries the film and returns the chip to a waiting cell. The Recorder throughput is 240 thousand bits per second, the recording cycle takes about 18.5 seconds per chip at a minimum. Development keeps pace with the recorder by processing chips simultaneously in a carousel - assembly-line fashion at eight sequential developer stations. Complete processing of an individual chip takes about 150

seconds.

The Reader opens the cell, extracts the addressed chip, and positions it in front of a cathode ray tube flying spot scanner. A servo mechanism and associated electronics position the flying spot onto a line or track of data (track is the lowest addressable level) and scan the recorded bit patterns. Information is scanned from the chip at an instantaneous rate of 2.5 million bits per second. The multi-chip sequential maximum read rate is approximately 1.1×10^6 data bits per second. Any cell can be accessed in less than three seconds. Since this device (or technique) uses non-erasable storage and has recording speeds that are much slower than reading speeds, it would be particularly suitable applications requiring archival storage of data.

6. Other Devices

Three mainframe manufacturers are working on prototype trillion-bit memory systems, they are IBM, Honeywell and Control Data. These systems are as yet unannounced, but will be described briefly here.

The IBM system magnetically records at a 6600 bits per inch linear density on 9,600 cartridges with each cartridge containing seven million characters. The total capacity of the system is 540 trillion bits. Each cartridge contains 120 inches of three inch wide tape. Thus there are 800,000 bits per track and 70 tracks on the three inch wide tape. Access time for a physical unit in the system is 5.4 to 7.4 seconds and the time to access a record is 30

msec track to track. The unit uses a special head for recording and has 16 read/write heads.

The Control Data SCROLLER system uses 5,000 foot magnetic tape divided into 1,000 segments. Each segment has 2,046 tracks across the 22-inch wide tape and each track within the segment can hold 240,000 bits for a total capacity of a trillion bits in a two-tape system. Access time for a physical unit is .5 sec and for a record it is 33 msec/revolution with five revolutions maximum.

The Honeywell Project MASS uses a thin metal film on a thick glass substrate and an electron beam to irreversibly alter the film. Each module in the system has 50,000 pages and each page contains 4,500 lines each with 4,500 bits for a total capacity of one trillion bits per module. Average access time for a physical unit is 100 msec average to move a table and ten msec to 30 msec for serial block to block; 140 msec is said to be the worst access time. Access time for a record within a page is then 100 micro-seconds.

D. <u>Comparison of Mass Storage Systems</u>

Ampex, Grumman, Unicon and IBM (1360) all have operational models of their particular systems in production. International Video has an operational IVC-1000 but as of this date has not started production. The RCA holographic memory is still in the development stages.

Table V contains a summary of some performance capabilities of the operational models that have been

discussed. The RCA holographic memory has a capacity of 10^8 bits but an access time of only 100 microseconds. An increase in access time would result if a capacity of a trillion bits were implemented due to a need for mechanical mechanisms. Holographic memories still are in an engineering stage. The RCA holographic memory was not included in Table V since it is not yet an operational product.

	TERABIT	IVC-1000	MASSTAPE	IBM 1360	UNICON
CAPACITY (BITS)	3×10^{12}	1.0×10^{12}	1.0×10^{12}	0.95×10^{12}	0.7×10^{12}
LOWEST ADDRESSABLE LEVEL/CAPACITY IN BITS	BLOCK/10^6	TRACK/1.2×10^5	HALF-TRACK FILE/1.15×10^7	FRAME/ 2×10^5	RECORD/ VARIABLE
AVERAGE ACCESS TIME (SECONDS)	13.3	90	5.8	3	10.15
TRANSFER RATE (PER CHANNEL) $\frac{\text{bit}}{\text{SEC}}$	6×10^6	8×10^6	1.2×10^6	2.5×10^6	3.4×10^6
ESTIMATED PRICE (MILLION DOLLAR)	3	.65 12 DRIVES + 1 CONTR	1.2	---	1.6
PRICE PER MILLION BITS	$1.07	$0.65	$1.20	---	$1.60

TABLE V SUMMARY OF MASS STORAGE CAPABILITIES

IV. ANALYSIS OF UNICON MASS MEMORY SYSTEM

In this section, the UNICON laser mass memory will be discussed. The system organization of the UNICON with respect to the hardware configuration of the UNICON and the software requirements are presented in part A. A file organization is chosen in part B, then, in light of this organization, the following routines are discussed: file maintenance, data retrieval, report generation and sorting. In part C, formulas for the various routines in part B will be developed and graphs will be utilized to highlight significant facts.

A. SYSTEM ORGANIZATION

1. Hardware Configuration

Figure VI is a drawing of the hardware configuration for the UNICON mass memory system that was used in the performance and applications analysis. There are two read/write stations each controlled by a separate word processor. The control computer then controls the word processors and the flow of information between the staging disks and the host computer. Each read/write station has an I/O channel that is double buffered for effective continuous data flow between the read/write stations and the staging disks.

2. Software Requirements

Precision Instrument Company provides the software required to control the data accesses both to and from the

data strips as well as providing maintenance programs and system diagnostic routines. Precision Instrument Company also supplies the software necessary for any interface requirements.

B. SYSTEM FUNCTIONS

1. File Organization

To store the address of every record that is recorded on the UNICON memory would involve an extremely large VTOC (volume table of contents) to be kept by a host computer, perhaps as large as 18×10^{8} bits. Therefore, it is reasonable to make use of the mass memory to keep track of the recorded data sets. For this purpose a STOC (strip table of contents) is recorded in the first track of every strip. Thus, the host computer need only know the strip number of a given record. This STOC contains the track and relative address within that track of all records recorded on the given strip. The STOC must be loaded into the control computer every time a new strip is mounted.

The method with which records will be physically recorded on a data strip must also be considered. Let's assume the use of fixed length records and that there is one record per physical block. A number of possibilities are as follows:

a. The simplest method would be to write the data from track one sequentially to track 11,440. For archival storage, whether for sequential or random retrieval, this

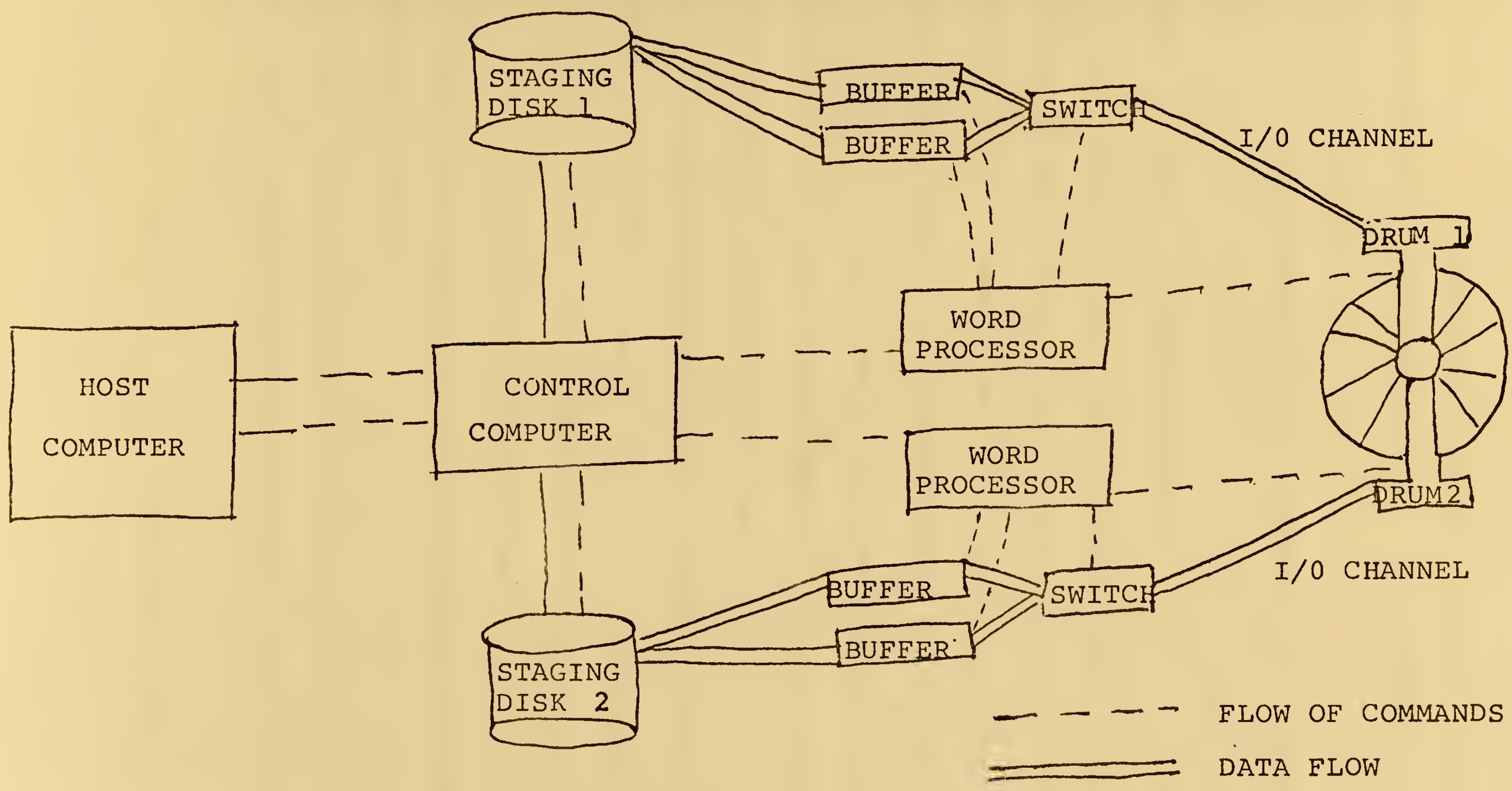


FIGURE VI. UNICON HARDWARE CONFIGURATION

would be the most economic solution. If, however, file maintenance is necessary, then this method would result in all changed and inserted records on another strip, a very undesired result.

b. Considering file maintenance, another method would be to record on track (i) and then skip track (i + 1) leaving it for any updates, insertions, etc., of records for track (i). Within this same general idea, data could be recorded on the first so many tracks of a strip and then leave so many vacant dependent upon the activity factor of a given data set. If we assume that file maintenance is performed on a record and that a whole track must not be rewritten due to one updated record, then this method will result in a large amount of track switching. If, however, every time you wish to update a record, a whole track must be rewritten, then a large amount of blank space will be needed for a file with a high update activity.

c. Another method would be to record sequentially from track one to 11,440, leaving no empty tracks, but each track would be only partially filled, leaving empty space for file maintenance of any record on the given track. Thus, in file maintenance operations track switching is greatly reduced.

For purposes of this discussion, method three will be used as the file organization scheme.

2. File Maintenance

File maintenance as applied to the UNICON mass memory system using the third file organization method will now be described. The empty space on each track will be referred to as update space. This update space is a function of the file maintenance mode, i.e., batch or terminal processing; the number of file changes per day; the life of the strip in days; and the activity factor within a file. For the present discussion, batch processing will be the assumed file maintenance mode, and this will only occur once a day (this does not restrict the query or report activities). The life of the strip depends on how much space is allocated for updates and how many days it takes to fill this space. For example, if data is stored archivally, then the strip life would be indefinite. The activity factor indicates the percentage of the records within a file which are accessed on updates. For example, an activity factor of .1 indicates that every tenth record will be accessed. A further assumption is that all times calculated will be effective, implying both read/ write stations will be used.

Every day that we perform file maintenance on a given strip, a new STOC must be written. Due to the permanent recording of data, this information must be stored in new tracks daily, under the assumption made above. Thus, depending on the life of the strip, that number of tracks must be left vacant at the beginning of each strip. For example, if the life of the strip was determined to be 15 days, then

enough tracks for 15 STOC's must be left at the beginning of each strip. When these STOC tracks are all filled, the current information must be written on a new strip and the old strip discarded.

With these thoughts in mind, the following file maintenance routines will be discussed:

a. Updating

In updating a file, records are passed from the mass memory to the host computer, where the actual record is changed. After reading the STOC, the first step in file updating is to read out the entire track continuing the desired record or records onto the staging disk. The STOC residing in the control computer has the relative address of all records within the track, so that the desired records can be passed from the staging disk to the host computer. After the updated records written on the staging disk, the updated records only are then written into the update space of the proper track. A change in address is then made for the updated record in the STOC. Finally when all records on the strip have been updated, the modified STOC is written on the strip.

When updating records randomly across strips, it is better to read just the desired record rather than the whole track. This may also be true for files with very low activity factors. Support of this statement will be found later.

b. Insertions

The host computer locates the strip where the records have to be inserted. The proper strip is mounted and its STOC read into the control computer. The records to be inserted are placed on the staging disk as the host passes the relative addresses of the records to the control computer. The STOC is then updated and the inserted record written into the update space of the proper track. For random processing, a new STOC must be loaded generally.

c. Deletions

Again, the proper strip containing the file, where the records have to be deleted, has its STOC loaded into the control computer. The relative record addresses are then removed from the STOC thus disregarding the deleted records. The STOC must then be written back on to the proper strip which is the last operation in all file maintenance routines.

3. <u>Data Retrieval</u>

Assume a given strip has been used for a number of daily updates and now assume a simple data retrieval of a file on that strip, is made. As previously mentioned, the initial step for all procedures involving the mass memory, is to load the STOC of the desired strip into the control computer. As a result, access can then be made directly to any record on the mounted strip. Let's look at a track on the strip.

1	~~2~~	3	4	5	~~6~~	...	...	2	6

Suppose records one through six were initially recorded sequentially, but during file maintenance, records two and six have been updated and moved. As a result, the STOC points to positions in the update space for records two and six. To read these six records of the file, the control computer first initiates a word processor to control the movement of the optic head. Based on the relative position of a record within a track, the control computer will pass to the work processor the length of track to be read by the optic head. Thus, record one above will be read, then the word processor would be given a new location of the track to read record two. The same procedure occurs to read record three, except now the control computer sends the length of track for the next three sequential records to the word processor. The read procedure would then continue in this manner. If a strip contained archival information, the data would have been retrieved sequentially with no need for jumping back and forth within a track.

Another possible method for data retrieval would be to read the whole track into the buffer, then moving only one record at a time to the staging disk in the proper file sequence. This technique would, however, require the buffer to be addressable and at least have the capacity of a track,

i.e., 2 X 10^4 bytes. If records are retrieved randomly from the mass memory, the host computer must indicate the strip and have the STOC loaded into the control computer. Thus, if records are retrieved randomly across all strips, a lot of extra time will be used loading new strips and STOC's.

4. Report Generation

In report generation on the UNICON, a file will be read onto a staging disk where it will wait to be printed on a line printer or terminal. To generate a report of the records in a given file, the following takes place. First, the STOC of the desired strip is loaded, then the records are read in their proper file order onto the staging disk. That is, a segment of records in a track are read sequentially until reference is made to the update space of the track. Thus, if no updates were made on a given track, then the entire track short of the update space would be read sequentially. Once loaded onto a staging disk, a file is ready to be processed by a line printer.

5. Sorting

The UNICON System is not very well suited for sorting because is uses non-erasable storage and it becomes very expensive to continually move records as required during sorting. Also, the Unicon System has only two read/write stations which is not adequate for even a two way merge without a large amount of head movement.

Sorting could be accomplished external to the strips. By using the two staging disks and two external magnetic tape drives, the host computer could perform the merging of data stored in the laser memory. The size of the file that could be sorted would be determined by the capacity of the staging disks or of the external peripheral devices if their capacity is smaller than the disks.

C. PERFORMANCE EVALUATION

The object of this section is to present equations for calculating the performance of the routines discussed in the previous section, i.e., file maintenance, data retrieval, and report generating routines. Then, with some basic assumptions, graphs will be presented expressing the performance results calculated through the use of these formulas. Questions like: "Is there a great advantage to sequential processing over random processing in the use of the UNICON mass memory?", will be answered. Also, how low an activity factor could be tolerated in sequential processing, before it becomes more advantageous to skip over non-required records.

Before turning to each of the individual routines mentioned, some assumptions will be made for ease of computation.

1. The life of the strip will be 30 days.

2. The number of days a strip has been in use will be the mean of the life of the strip, in this case 15 days.

3. Fixed length records will be assumed.

4. The STOC will require nine tracks which is dependent upon a record size of 10^3 bytes. This record size was chosen for reasons that will be shown later. Actually, a record size of 10^4 bytes would have only required one track for an STOC.

The variables that will be used should also be defined at this point.

- NRECTR - number of records on a track
- N_1 - number of records
- r_1 - record size (Bytes)
- TRLEN - track length, 31 inches
- LINDEN - linear density, 612 bytes/inch
- AF - activity factor, ranges from 0 to 1
- LS - life of the strip in days
- NU - number of days, strip has been in use (days)
- K - the fraction of a track, that will initially be recorded, this is a function of the activity factor and the life of a strip.

1. <u>Data Retrieval</u>

For data retrieval of a sequential file, it is first necessary to load the STOC, then sequentially transfer the file, track by track. The following formula represents data retrieval of a file in sequential processing.

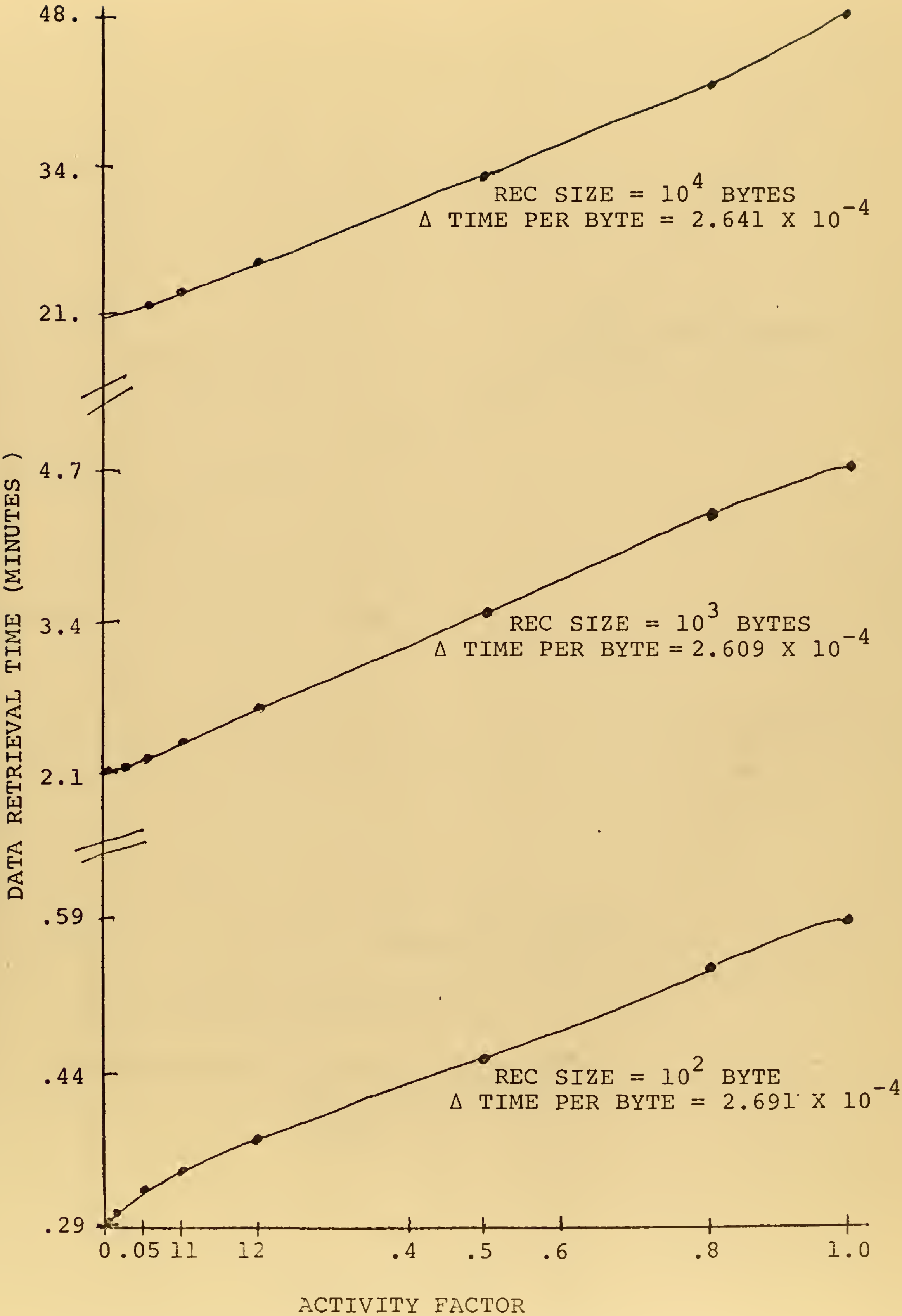
DATA RETRIEVAL TIME = ACCESS TIMES WITHIN TRACK
+ TRACK SWITCHING TIME
+ STRIP ACCESS TIME
+ STOC TRANSFER TIME
+ DATA TRANSFER TIME

$$= (AD \cdot NRECTR \cdot NU)\ (40\ \text{msec})$$
$$+ 130\ \text{msec} + \left(\frac{N_1}{NRECTR}\right)\ (2\ \text{msec})$$
$$+ 45\ \text{msec}$$
$$+ \frac{N_1 r_1}{.425 \times 10^6\ \text{byte/sec}}$$

Where $NRECTR = \frac{(K)\ (TRLEN)\ (LINDEN)}{r_1}$

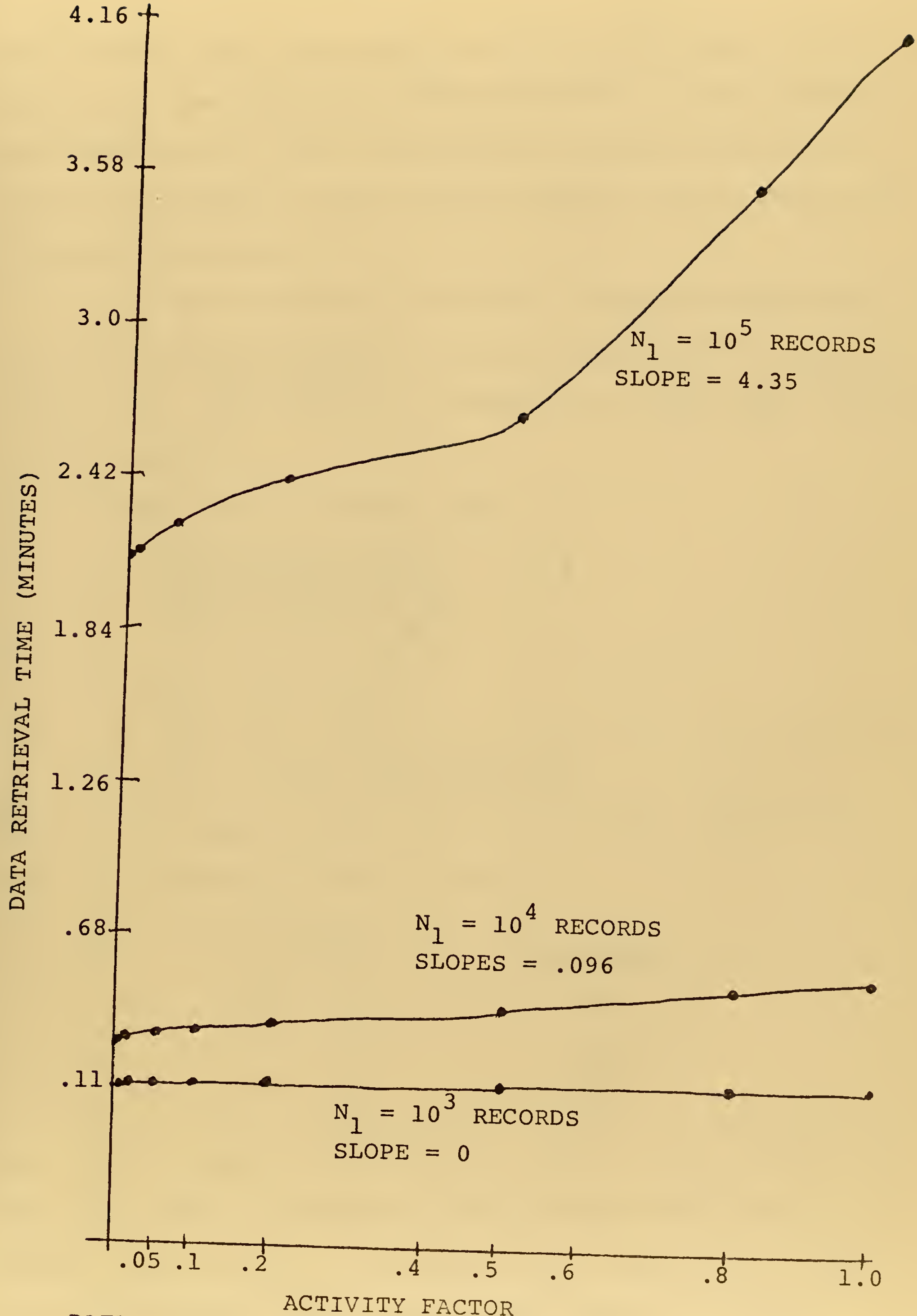
Figure 7, a data retrieval time for various record sizes, is used to find an optical record size. Holding the number of records N_1, fixed at 10^5 records and then varying the activity factor for record sizes 10^2, 10^3, and 10^4 bytes, resulted in the 10^3 curve having the smallest change in time per byte. Also, for an activity factor of .001, the data retrieval time per byte is .0028, .0021, and .0020 minutes respectively. Note that the change in time per byte levels off between 10^3 and 10^4 byte record sizes. As a result, it seems a fair assumption to use a record size of 10^3 bytes unless otherwise stated. As previously mentioned, a record size of 10^3 bytes requires nine tracks for each STOC, whereas a record size of 10^4 bytes requires only one track for the STOC. By assuming a record size of 10^3 bytes in this model, 2.5% of the storage will be used for record address tables.

Figure 8 is a data retrieval time versus activity factor graph for file sizes of 10^3, 10^4, and 10^5 records. The order of times shown for these file sizes is as expected, but for a file size of 10^5 records the time increases four times as fast as for 10^4 records as the file activity factor



DATA RETRIEVAL TIME FOR VARIOUS RECORD SIZES

FIGURE 7



DATA RETRIEVAL TIME FOR VARIOUS FILE SIZES

FIGURE 8

goes to one. For a file size of 10^3 records, there is no appreciable time increase in data retrieval as the activity factor increases. Note that when the activity factor is 0, the time indicated is for retrieval of an archival store for the given file size.

For data retrieval of records randomly across the 450 strips, it is necessary to load a new STOC 99.77 percent of the times. Following is a formula for random data retrieval of N_1 records.

RANDOM DATA RETRIEVAL TIME

= RECORD ACCESS TIME
+ STOC TRANSFER TIME
+ RECORD TRANSFER TIME

$$= (N_1)\ (10,147 \text{ msec})$$
$$+ (N_1)\ (44.9 \text{ msec})$$
$$+ (N_1)\ \frac{(r_1)}{(.425 \times 10^6 \text{ byte/sec})}$$

Where 10,147 msec includes the time to load a strip. To retrieve a record of size r_1 takes:

r_1 (Bytes)	Time (Min.)
$10^1 - 10^4$	.085
10^5	.086
10^6	.105

Then, for the time to retrieve N_1 records, just multiply N_1 times the TIME in minutes for the desired record size. For example, to retrieve 10^5 records, where record size is 10^3 bytes, would take 8,495 minutes which equals 5.9 days.

2. Updating

In sequential processing, to update a file with a given activity factor, it was assumed the entire track containing the desired record would be read into the staging disk. The updated record alone would be rewritten in the update space of the given track. The time to sequentially update a file of N_1 records with an activity factor AF, is the time to retrieve the desired tracks and then the time to rewrite the updated records.

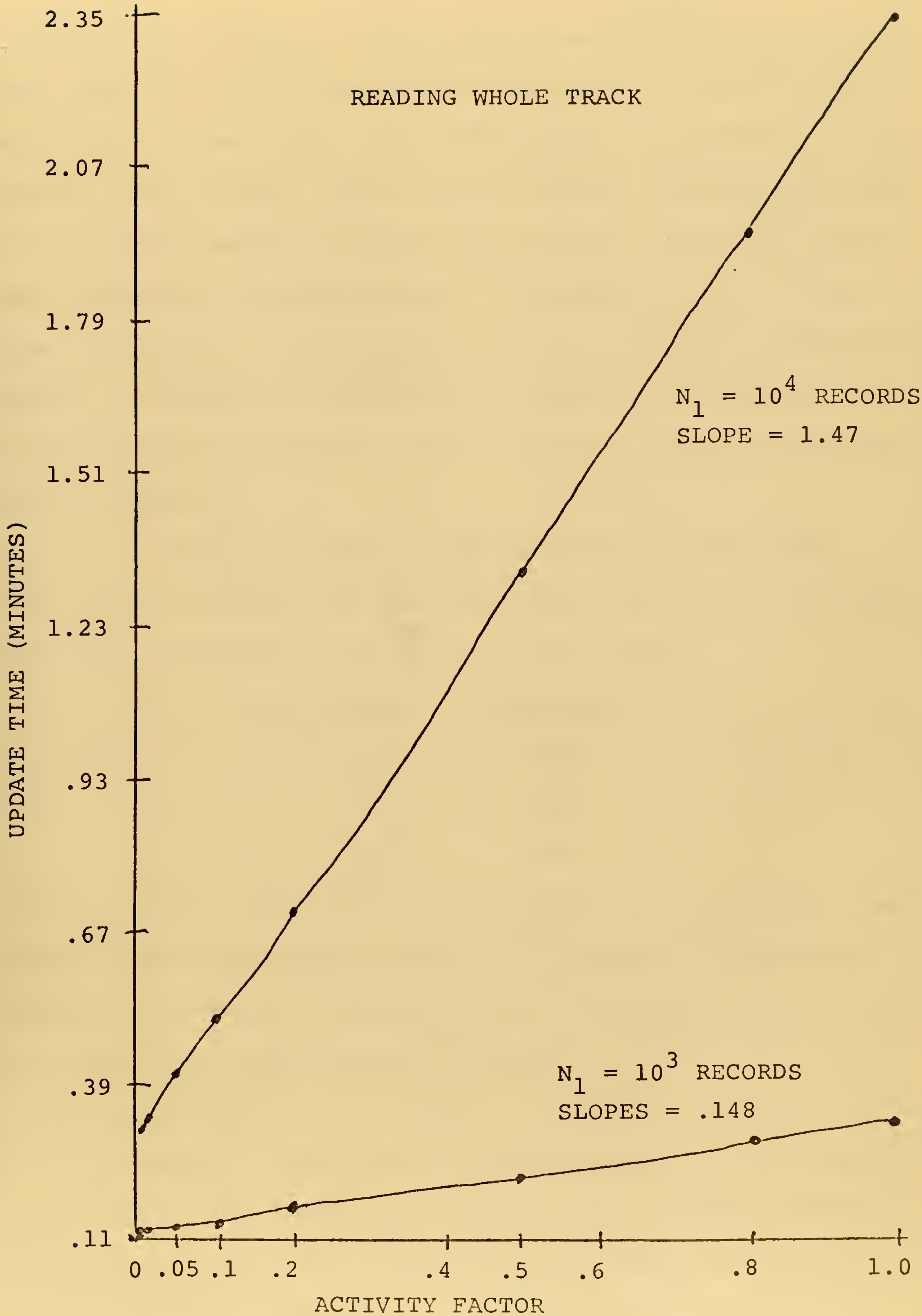
UPDATE TIME = DATA RETRIEVAL TIME

+ TIME TO ACCESS UPDATE SPACE
+ TIME TO WRITE UPDATED RECORD

$$= \text{DATA RETRIEVAL TIME} + (AF \cdot N_1)\ (20 \text{ msec.}) + (AF \cdot N_1)\ (r_1)\ (1600 \times 10^{-6} \text{ msec}).$$

Figure 9 displays the time curves to sequentially update files of 10^3 records and 10^4 records. Note that the update time for a 10^4 record-file increases 10 times faster than for a file of 10^3 records. As a result, on the 10^4 record curve, a significant increase in time from an activity of .001 to .01 can be seen as compared to the 10^3 record curve.

For a file with a low activity factor, it would seem more advantageous to read just the desired records into the staging disks rather than an entire track. Figure 9 shows two time curves for sequentially updating 10^5 record-file, with 10^3 bytes per record. Curve A depends on reading



UPDATE TIME READING WHOLE TRACK

FIGURE 9

entire tracks of data, while curve B was calculated using data retrieval of the desired records only. Note for low activity factors, there is a substantial improvement in only reading the records. Even as the activity factor approaches 1, a slight advantage is still maintained, indicating that the technique of reading only the desired records is more time economic. Of significance is the fact that in comparing curve A of figure 10 with the 10^4 record curve of figure 9, no significant difference in the change in time per activity factor exists.

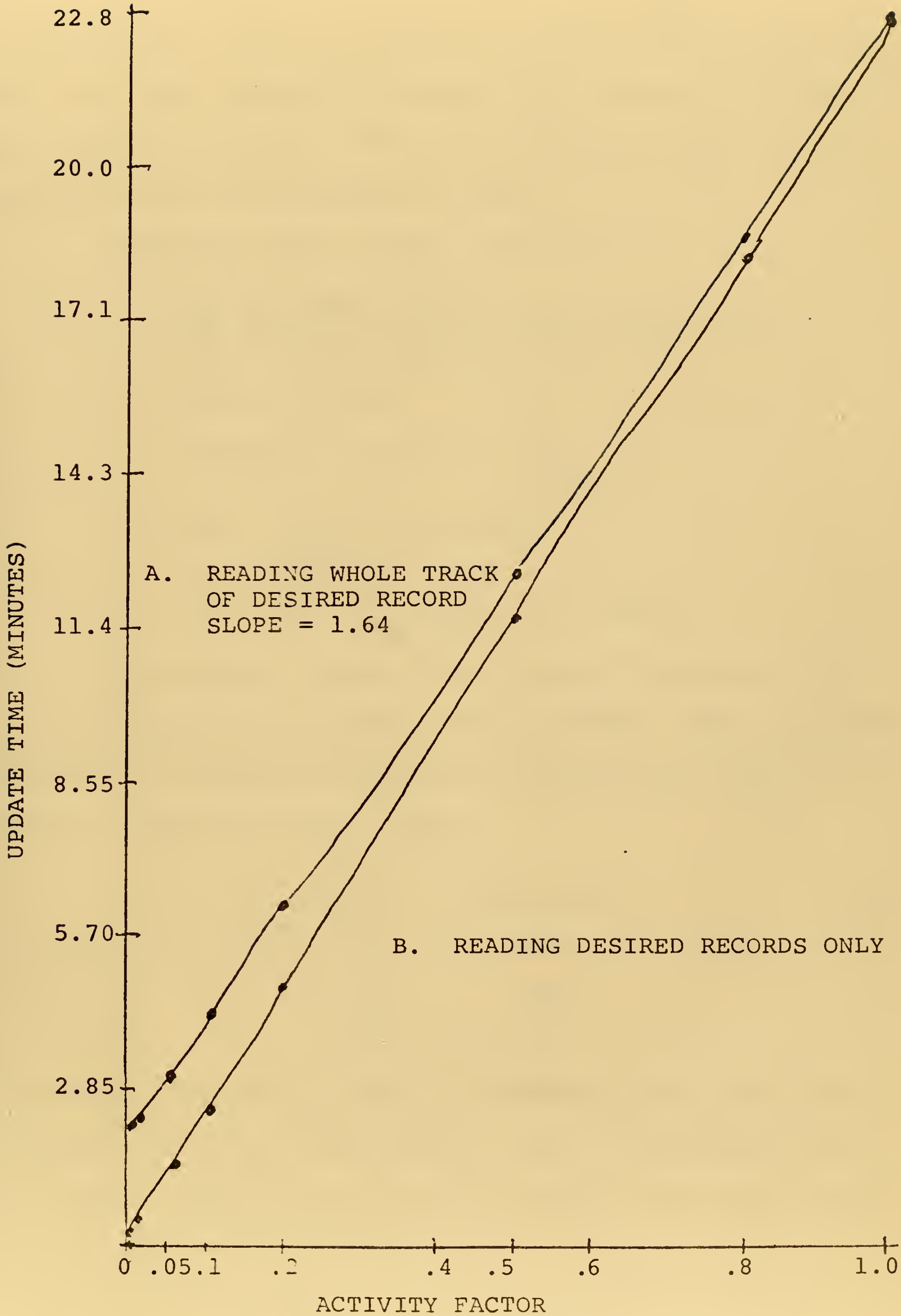
To randomly update N_1 records requires the same write time as above, but now the random data retrieval times are used. To update a record of size r takes:

r. (Bytes)	Time (min.)
10^1 - 10^4	.085
10^5	.085
10^6	.118

For N_1 records, just multiply the TIME by N_1 to get the desired file size update time. For example, to randomly update 10^5 records, each record being 10^3 bytes, would take 8,513 minutes, which equals 5.9 days.

3. Insertions

Figure 10 shows record insertion time versus activity factor curves for sequential processing of record insertions into a given file. Of interest is the sudden acceleration of the 10^5 record curve for an activity factor above .2. For example, if a file of 10^5 records has an activity factor



UPDATE TIME COMPARISON

FIGURE 10

of one, it will take 55 minutes to insert 10^5 more records into that file versus four minutes for a file of 10^4 records with the same activity. The statistics for figure 11 were gathered using the following formula.

INSERTION TIME = TIME TO READ STOC

+ TIME TO ACCESS TRACKS
+ TIME TO ACCESS UPDATE SPACE WITHIN TRACK
+ TIME TO WRITE INSERTED RECORD

$$= 4.5 \times 10^{-2} \text{ sec}$$

$$+ \left(130 \text{ msec} + (2 \text{ msec}) \frac{(N_1)}{(NRECTR)} \right)$$

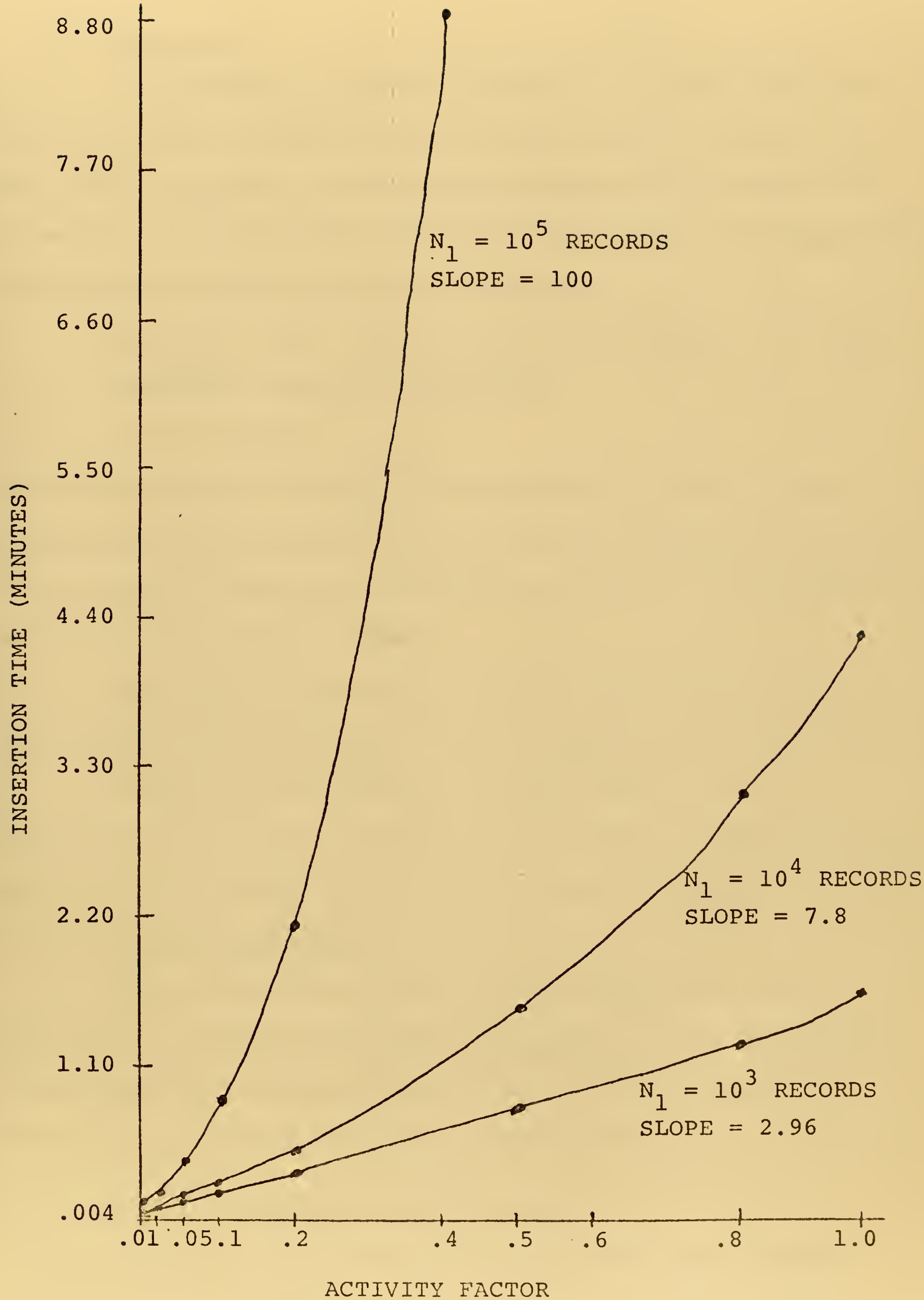
$$+ (AF) \frac{(N_1)}{(NRECTR)} (20 \text{ msec})$$

$$+ (AF) (N_1) (r_1) (1600 \times 10^{-6} \text{ msec})$$

To randomly insert records across the strips that 99.77% of the time, the STOC must be loaded. The following table is an example of random record insertion times. To insert a record of size r takes:

r_1 (Bytes)	Time (min.)
$10^1 - 10^4$	.085
10^5	.086
10^6	.098

To randomly insert N_i records it takes N_1 times the TIME above for the given record size. Thus, to randomly insert 10^5 records, each record being 10^3 bytes, would take 8,478 minutes which equals 5.9 days.



INSERTION TIME GRAPH

FIGURE 11

4. Deletions

To sequentially delete records in a file, with given activity factor, requires only that the STOC be loaded into the control computer, where address change will be made as a result of the deletions. When the operation is through the STOC must be written back to a new track.

DELETION TIME = TIME TO READ STOC + 2 MSEC FOR TRACK TO TRACK + TIME TO WRITE STOC

= 77.4 msec.

The actual address changing time performed in the control computer is not included; this, of course, would be a function of file size, record size and activity factor, but should be small enough to be negligible.

To randomly delete N_1 records across the strips implies the following rule,

RANDOM DELETION TIME = N_1 (77.4 msec).

Random deletion time is a factor of N_1 greater than sequential deletion of N_1 records in a file with activity factor of one.

5. Report Generation

Using the definition of report generation given earlier, it requires the same operations as data retrieval, whether random or sequential. Thus, the data retrieval formulas can be used for report generation.

D. PERFORMANCE EVALUATION CONCLUSIONS

In conclusion, a comparison of sequential and random processing for both a small file and a large file will be

considered. The following data will be the basis for the comparison, assuming a record size of 10^3 bytes:

1. Sequential Processing (Minutes)

	File A = 10^8 AF = .001, N = 10^5	File B = 10^5 AF = .001, N = 10^2
Data Retrieval	92.0	.18
Updating	110.1	.20
Insertion	93.0	.09

2. Random Processing (Minutes)

	File A = 10^8 N = 10^5	File B = 10^5 N = 10^2
Data Retrieval	8,500	.21
Updating	8,500	.23
Insertion	8,500	.23

In the example above, File A spans the 450 strips, while File B is contained within two strips, which will remain mounted. In sequential processing of File A, an activity factor of .001 is assumed, resulting in 10^5 records actually being retrieved, updated or inserted, whereas only 10^2 records will be modified in File B. In random processing of File A and File B, 10^5 and 10^2 records, respectively, will be modified. It can be concluded that for a large file size, sequential processing is several orders of magnitude faster than random processing on the UNICON for a low activity factor. However, for files that remain on two strips or less, no significant difference is found between sequential and random processing of data.

Suppose now we assume an activity factor of .5 for sequential processing of File A and B, implying we will need to randomly process .5 X 10^8 and 15 X 10^2 records, respectively. The data retrieval times in sequential processing of File A and File B are now 2400 minutes and 1.7 minutes respectively. While, for random processing, the data retrieval times of File A and B are 4,250,000 minutes and 2.5 minutes respectively. The gap between sequential and random processing for a large file system has increased by another order of magnitude, while for the two strip file, only a slight increase in time for random processing over sequential processing has occurred. Thus, random processing is not practical for processing against a large file, but is quite practical against a file size of less than 4 X 10^6 bits (capacity of two strips).

Note that in an application calling for archival storage of data, data retrieval and report generation would be the only routines which are applicable. The lowest entry in the data retrieval statistics was always for an activity factor of 0, which is analogous to an archival store. Also notice that in all cases, increasing the activity factor from 0.0 to 0.1 resulted in operation time changes of less than a tenth of a minute, which is almost insignificant.

It can be concluded, then, that the UNICON mass memory is best suited for archival storage of data. If, however, archival storage is not used, it is more economic to use the UNICON mass memory in a sequential processing mode, rather than for random processing. Also for low file

activity factors in sequential processing, more records can initially be recorded per track.

V. CONCLUSIONS

In the conventional devices utilizing higher density techniques, performance improvements can be found generally by using the devices offered by the independent manufacturers, and almost always at a substantial cost saving.

The mass storage devices and systems are opening up a new market in the computer industry. The systems presented here offer capable solutions to the mass storage problem, from an engineering standpoint, but the operational qualities of these devices have yet to be measured due to the skepticism of the computer industry to accept new devices.

There is room for further work in the evaluation presented. The figures that have been collected for data retrieval, file maintenance and report generating could be compared with similar statistics generated by a 2314 disc drive, a 3330 disc drive or a standard fixed-head drum. It is necessary to see how realistic these statistics are. Also of importance might be the cost of allowing file maintenance for the various activity factors, compared with the cost of the system and the operation of the system. Finally, other file organizations should be compared with the one chosen here, specifically, an organization that is not record addressable, but rather block addressable with many records per block. The analysis performed in this report for the UNICON could also be performed for any of the other systems previously mentioned.

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13. ABSTRACT

With the need for storage of greater volumes of data, new technology has emerged in high density recording of data. First, a review is made of the conventional magnetic storage devices, including tapes, drums, and discs, and their double density replacements. A detailed analysis of disc storage devices is included. Mass storage units with very high recording densities will then be discussed. First, the different approaches taken toward mass storage will be presented, followed by an example of each approach. Finally, one of these example systems, a laser mass memory system called UNICON, will be analyzed with respect to file organization and I/O routines.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Magnetic High Density Recording						
Double Density Recording						
Trillion Bit Memory						

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